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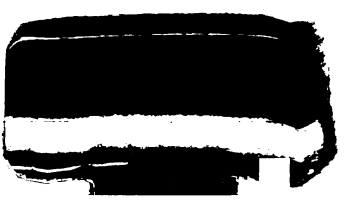

SUPPLEMENT

TO THE

THEORY, PRACTICE, AND ARCHITECTURE

OF

BRIDGES;

ILLUSTRATING THE MOST RECENT APPLICATIONS OF

CAST AND WROUGHT IRON, STONE, AND TIMBER, AND SUSPENSION;

WITH

OBSERVATIONS UPON THE DIFFERENT MATERIALS EMPLOYED IN THE CONSTRUCTION OF BRIDGES.

With Engravings, and Text.

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AN INQUIRY

INTO THE

APPLICATION OF IRON TO RAILWAY STRUCTURES.

THE Commissioners appointed by Her Majesty's Commission of the 27th day of August, 1848, to inquire into the conditions to be observed by engineers in the application of iron to structures exposed to violent concussions and vibration, and to endeavour to ascertain such principles and form such rules as may enable the engineer and mechanic, in their respective spheres, to apply the metal with confidence, and also to illustrate, by theory and experiment, the action which takes place under varying circumstances in iron railway bridges which have been constructed, beg dutifully to submit that we have called before us such persons as we judged most competent, by reason of their situation, knowledge, and experience, to afford us correct information on the subject of this inquiry. We have also obtained from such persons detailed answers in writing to many questions on subjects connected with their peculiar knowledge and experience as to the use and properties of iron. We have instituted and carried on many experiments upon this metal, and have personally examined the construction and action of several existing railway bridges.

From the information supplied to the Commissioners of this inquiry, it appears that the proportions and forms at present employed for iron structures have been generally derived from numerous and careful experiments, made by subjecting bars of wrought or cast iron of different forms to the action of weights, and thence determining, by theory and calculation, such principles and rules as would enable these results to be extended and applied to such larger structures and loads as are required in practice. But the experiments were made by dead pressure, and only apply, therefore, to the action of weights at rest. On the contrary, from the nature of the railway system, the structures employed therein are necessarily exposed to concussions, vibrations, torsions, and

momentary pressures of enormous magnitude, produced by the rapid and repeated passage of heavy trains.

These disturbing causes, in a smaller degree, have always occurred in structures connected with mill-work or other mechanism. But the effects upon their stability have not been found greater than could be met by increasing the dimensions of the parts, without especially inquiring into the exact principles upon which such increase should be made. Thus, we are informed that the dimensions of cast-iron girders intended for sustaining stationary loads, such as water-tanks and floors, are usually so proportioned that their breaking-weight shall be three times as great as the load they are expected to carry, or in some cases four or five times as great. But when the girders are intended for railway-bridges, and therefore subject to much concussion and vibration, greater strength is given to them by altering the above proportions, and making the breaking-weight from six to ten times as great as the load, according to the practice of different engineers. On the other hand, some consider that one-third of the breaking-weight is as safe a load in the latter case as in the former.

As it soon appeared, in the course of our inquiry, that the effects of heavy bodies moving with great velocity upon structures had never been made the subject of direct scientific investigation, and as it also appeared that, in the opinion of practical and scientific engineers, such an inquiry was highly desirable, our attention was early directed to the devising of experiments for the purpose of elucidating this matter.

The questions to be examined may be arranged under two heads, namely,—

1. Whether the substance of metal which has been exposed for a long period to percussions and vibrations undergoes any change in the arrangements of its particles, by which it becomes weakened?

2. What are the mechanical effects of percussions, and of the passage of heavy bodies in deflecting and fracturing the bars and beams upon which they are made to act?

A great difference of opinion exists among practical men with respect to the first of these questions. Many curious facts have been elicited by us in evidence, which show that pieces of wrought iron which have been exposed to vibration, such as the axles of railway carriages, the chains of cranes, &c., employed in raising heavy weights, frequently break after long use, and exhibit a peculiar crystalline fracture and loss of tenacity, which is considered by some engineers to be the result of a gradual change produced in the internal structure of the metal by the vibrations. In confirmation of this, various facts are adduced, as, for instance, that if a piece of good fibrous iron have the thread of a screw cut upon one end of it by the usual process of tapping, which is always accompanied by much vibratory action, and if the bar be then

broken across, it will be found that the tapped part is a good deal more crystalline than the other portion of the bar. Others contend that this peculiar structure is the result of an original fault in the process of manufacture, and deny this effect of vibration altogether; whilst some allege that the crystalline structure can be imparted to fibrous iron in various ways, as by repeatedly heating a bar red-hot and plunging it into cold water, or by continually hammering it, when cold, for half an hour or more.

Mr. Brunel, however, thinks the various appearances of the fracture depend much upon the mode in which the iron is broken. The same piece of iron may be made to exhibit a fibrous fracture when broken by a slow heavy blow, and a crystalline fracture when broken by a sharp short blow. Temperature alone has also a decided effect upon the fracture; iron broken in a cold state shows a more crystalline fracture than the same iron warmed a little.

The same effects are by some supposed to be extended to cast iron.

We have endeavoured to examine this question experimentally in various ways.

A bar of cast iron, 3 inches square, was placed on supports about 14 feet asunder. A heavy ball was suspended by a wire 18 feet long from the roof, so as to touch the centre of the side of the bar. By drawing this ball out of the vertical position at right angles to the length of the bar, in the manner of a pendulum, to any required distance, and suddenly releasing it, it could be made to strike a horizontal blow upon the bar, the magnitude of which could be adjusted at pleasure, either by varying the size of the ball, or the distance from which it was released. Various bars (some of smaller size than the above) were subjected, by means of this apparatus, to successions of blows, numbering in most cases as many as 4000; the magnitude of the blow in each set of experiments being made greater or smaller, as occasion required. The general result obtained was, that when the blow was powerful enough to bend the bars through one-half of their ultimate deflection, (that is to say, the deflection which corresponds to their fracture by dead pressure,) no bar was able to stand 4000 of such blows in succession; but all the bars (when sound) resisted the effects of 4000 blows, each bending them through one-third of their ultimate deflection.

Other cast-iron bars of similar dimensions were subjected to the action of a revolving cam, driven by a steam-engine. By this they were quietly depressed in the centre, and allowed to restore themselves, the process being continued to the extent even, in some cases, of a hundred thousand successive periodic depressions for each bar, and at a rate of about four per minute. Another contrivance was tried by which the whole bar was also, during the depression, thrown into a violent tremor. The results of these experiments were, that when the depression was

equal to one-third of the ultimate deflection, the bars were not weakened. This was ascertained by breaking them in the usual manner with stationary loads in the centre. When, however, the depressions produced by the machine were made equal to one-half of the ultimate deflection, the bars were actually broken by less than nine hundred depressions. This result corresponds with and confirms the former.

By other machinery a weight equal to half of the breaking weight was slowly and continually dragged backwards and forwards from one end to the other of a bar of similar dimensions to the above. A sound bar was not apparently weakened by ninety-six thousand transits of the weight.

It may, on the whole, therefore, be said, that as far as the effects of reiterated flexure are concerned, cast-iron beams should be so proportioned as scarcely to suffer a deflection of one-third of their ultimate deflection. And as it will presently appear that the deflection produced by a given load, if laid on the beam at rest, is liable to be considerably increased by the effect of percussion, as well as by motion imparted to the load, it follows, that to allow the greatest load to be one-sixth of the breaking-weight is hardly a sufficient limit for safety even upon the supposition that the beam is perfectly sound.

In wrought-iron bars no very perceptible effect was produced by 10,000 successive deflections by means of a revolving cam, each deflection being due to half the weight which, when applied statically, produced a large permanent flexure.

Under the second head, namely, the inquiry into the mechanical effects of percussions and moving weights, a great number of experiments have been made to illustrate the impact of heavy bodies on beams. From these it appears, that bars of cast iron of the same length and weight struck horizontally by the same ball (by means of the apparatus above described for long-continued impact) offer the same resistance to impact, whatever be the form of their transverse section, provided the sectional area be the same. Thus a bar, $6 \times 1\frac{1}{2}$ inches in section, placed on supports about 14 feet asunder, required the same magnitude of blow to break it in the middle, whether it was struck on the broad side or the narrow one, and similar blows were required to break a bar of the same length, the section of which was a square of three inches, and, therefore, of the same sectional area and weight as the first.

Another course of experiments tried with the same apparatus showed, amongst other results, that the deflections of wrought-iron bars produced by the striking ball were nearly as the velocity of impact. The deflections in cast iron are greater than in proportion to the velocity.

A set of experiments was undertaken to obtain the effects of additional loads spread uniformly over a beam, in increasing its power of bearing

impacts from the same ball falling perpendicularly upon it. It was found that beams of cast iron, loaded to a certain degree with weights spread over their whole length, and so attached to them as not to prevent the flexure of the bar, resisted greater impacts from the same body falling on them than when the beams were unloaded, in the ratio of two to one. The bars in this case were struck in the middle by the same ball falling vertically, through different heights, and the deflections were nearly as the velocity of impact.

We have also carried on a series of experiments to compare the mechanical effect produced by weights passing with more or less velocity over bridges, with their effect when placed at rest upon them. For this purpose, amongst other methods, an apparatus was constructed, by means of which a car loaded at pleasure with various weights was allowed to run down an inclined plane; the iron bars which were the subject of the experiment were fixed horizontally at the bottom of the plane in such a manner that the loaded car would pass over them with the velocity acquired in its descent. Thus the effects of giving different velocities to the loaded car, in depressing or fracturing the bars, could be observed and compared with the effects of the same loads placed at rest upon the bar.

This apparatus was on a sufficiently large scale to give a practical value to the results; the upper end of the inclined plane was nearly 40 feet above the horizontal portion; and a pair of rails, 3 feet asunder, were laid along its whole length for the guidance of the car, which was capable of being loaded to about 2 tons; the trial bars, 9 feet in length, were laid in continuation of this railway at the horizontal part, and the inclined and horizontal portions of the railway were connected by a gentle curve. Contrivances were adapted to the trial bars, by means of which the deflections produced by the passage of the loaded car were registered; the velocity given to the car was also measured, but that velocity was, of course, limited by the height of the plane, and the greatest that could be obtained was 43 feet per second, or about 30 miles an hour.

A great number of experiments were tried with this apparatus, for the purpose of comparing the effects of different loads and velocities upon bars of various dimensions, and the general result obtained was that the deflection produced by a load passing along the bar was greater than that which was produced by placing the same load at rest upon the middle of the bar, and that this deflection was increased when the velocity was increased. Thus, for example, when the carriage loaded to 1120 lbs. was placed at rest upon a pair of cast-iron bars, 9 feet long, 4 inches broad, and $1\frac{1}{2}$ inch deep, it produced a deflection of $\frac{6}{10}$ths of an inch; but when the carriage was caused to pass over the bars at the rate of 10 miles an hour, the deflection was increased to $\frac{8}{10}$ths, and went on increasing as the velocity was increased, so that at 30 miles per

hour the deflection became $1\frac{1}{8}$ inch; that is, more than double the statical deflection.

Since the velocity so greatly increases the effect of a given load in deflecting the bars, it follows that a much less load will break the bar when it passes over it than when it is placed at rest upon it, and accordingly, in the example above selected, a weight of 4150 lbs. is required to break the bars if applied at rest upon their centres; but a weight of 1778 lbs. is sufficient to produce fracture if passed over them at the rate of 30 miles an hour.

It also appeared that when motion was given to the load, the points of greatest deflection, and, still more, of the greatest strains, did not remain in the centre of the bars, but were removed nearer to the remote extremity of the bar. The bars, when broken by a travelling load, were always fractured at points beyond their centres, and often broken into four or five pieces, thus indicating the great and unusual strains they had been subjected to.

We have endeavoured to discover the laws which connect these results with each other and with practice, and for this purpose a smaller and more delicate apparatus was constructed to examine the phenomena in their simplest form, namely, in the case of a single weight traversing a light elastic bar. For the weight in its passage along the bar deflects it, and thus the path or trajectory of the centre of the weight, instead of being a horizontal straight line, as it would be if the bar were perfectly rigid, becomes a curve, the form of which depends upon the relation between the length, elasticity, and inertia of the bar, the magnitude of the weight and the velocity imparted to it. If the form of this curve could be perfectly determined in all cases, the effects of travelling loads upon bars would be known; but, unfortunately, the problem in question is so intricate that its complete mathematical solution appears to be beyond the present powers of analysis except in the simplest and most elementary case, namely, in which the load is so arranged as to press upon the bar with one point of contact only, or, in other words, the load is considered as a heavy moving point. In practice, on the contrary, a single four-wheeled carriage touches each rail or girder in two points, and a six-wheeled engine with its tender has five or six points in contact on each side. This greatly complicates the problem.

The above smaller apparatus is so arranged as to comply with the simple condition that the load shall press upon one point only of the bar, and is also furnished with a contrivance by which the effects of various proportions of the mass of the bar to that of the load can be examined. From the nature of the problem, it is convenient to consider, in the first place, the forms of the trajectories that are described, and the corresponding deflections of the bar, when the mass of the bar is exceedingly small compared with that of the load.

Having obtained these under different relations of the length of the

bridge, its statical deflection, and the velocity of the passing load, we proceed to investigate, in addition, the effect which a greater proportional mass of the bar or bridge has upon the deflections. We have been greatly assisted in this research by a most elaborate and complete analytical investigation by George Stokes, Esq., Fellow of Pembroke College, Cambridge, undertaken at the request of one of the members of the Commission. Unfortunately, the extreme difficulty of the problem has rendered its solution unattainable excepting in the cases in which the mass of the bridge is supposed to be exceedingly small compared with that of the load, and in the opposite case, in which the mass of the load is supposed to be small compared with that of the bridge. The examples that occur in practice lie between these two extremes; for in the experiments of the Commission, performed at Portsmouth, with the inclined plane already described, the weight of the load was from three to ten times that of the bar; but this is a much greater proportion than that which occurs in bridges, partly on account of the necessity for employing in experiments very flexible bars, to render the changes of deflection sufficiently apparent, and partly on account of the great difference of length; for if bars bearing the same ratio of weight to that of the load were employed in experiment, the deflection would become so small as to be scarcely appreciable. This will readily be perceived when it is stated that, in a bridge of 30 feet long, a deflection not greater than one-fourth of an inch is usually allowed, which deflection is only one 1440th part of its length; whereas in experiment it is necessary to employ deflections of two or more inches. In actual bridges of about 40-feet span, the weight of the engine and tender is very nearly the same as the weight of that half of the bridge over which it passes; and in large bridges the weight of the load is much less than that of the bridge.

Mr. Stokes has shown that when the inertia of the bridge is supposed small, the trajectories of the load and the corresponding deflection of the bridge depend upon a certain quantity, which he terms β; this quantity varies directly as the square of the length of the bar, and inversely as the product of the central statical deflection (namely, that which would be produced by the load set at rest on the centre of the bridge), and of the square of the velocity with which the load passes over the bridge. When β is small, the increase of deflection due to the velocity of the load becomes very great, so much so that if β be equal to 1·3, the statical deflections are doubled, and are tripled when $\beta = 0{\cdot}8$; becoming still greater as lesser values of β are taken. On the contrary, greater values of β correspond to small deflections; and it has been shown by our researches that, in the cases of real bridges, β is rarely less than 14, and is commonly very much greater; and that, consequently, the greatest increase of deflection from velocity would be upon this

theory never greater than one-tenth, varying from that to one-hundredth or less. As β varies directly as the square of the length of the bridge, it is plain that the 9-feet bars of the Portsmouth experiments will correspond to much less values of β than the 20 and 30-feet lengths of actual bridges; while the values of β in the former cases are still further diminished by the greater deflections necessarily employed in experiments, as above explained. It is thus shown that the enormous increase of deflection produced by velocity in the Portsmouth experiments cannot occur with real bridges, since it appears that the phenomena in question are developed to a great extent when the magnitude of the structure is diminished. But these calculations are made upon the supposition that the inertia of the bridge is very small; and experiments made with the small apparatus above mentioned have shown that, while β is less than about unity, the inertia of the bridge tends to diminish the deflection; while, on the other hand, when β is greater than unity (including, of course, all practical cases), the inertia of the bridge tends to increase the deflections obtained upon the above supposition. Lastly, the total increase of the statical deflection, when the inertia of the bridge is taken into account, will be found much greater for short bridges than for long bridges. Supposing, for example, the mass of the travelling load and of the bridge to be nearly equal, the increase of the statical deflection at the highest velocities for bridges of 20 feet in length and of the ordinary degree of stiffness may be more than one-half; whereas for bridges of 50 feet in length, the increase will not be greater than one-seventh, and will rapidly diminish as greater lengths are taken. But as it has been shown that the increase, *cæteris paribus*, is diminished by increasing the stiffness of the bridge, we always have it in our power to reduce its amount within safe limits. Hence, in estimating the strength of a railway bridge, this increase of the statical deflection must be taken into account, by calculating it from the greatest load which is likely to pass over the bridge, and from the highest possible velocity. It must be remembered also, that this deflection is liable to be increased by jerks produced by the passage of the train over the joints of the rails. In Appendix B* will be found the details of the above somewhat complicated investigation.

We also made some experiments by means of the large apparatus, before mentioned, on curved bars, and these bore much greater weights at high velocities than straight bars; but the deflections of these bars were very great, compared to their length. In drawing attention to these experiments, we would remark that, in actual structures, where the deflections are so very small, the effect of cambering the girders, or

* Report of the Commissioners appointed to inquire into the Application of Iron to Railway Structures. 2 vols. folio, 1850.

of forming a curved pathway for the load, would be of less comparative importance, and might tend to introduce practical inconvenience.

The general impression amongst engineers appears to be at variance with the above results. They, for the most part, state their belief that the deflection caused by passing a weight at a high velocity over a girder is less than the deflection which would be produced by the same weight at rest; even when they have observed an increase, they have attributed it solely to the jerks of the engine or train produced by passing over inequalities at the junction of the rails, or other similar causes.

For the purpose of examining this question, we have submitted two actual bridges to the test of experiment. These bridges, one of which, the Ewell Bridge, is situated upon the Croydon and Epsom line, and the other, the Godstone Bridge, upon the South Eastern line, are both constructed to carry the railway over a road. A scaffold was constructed which rested on the road, and was, therefore, unaffected by the motion of the bridge, and a pencil was fixed to the under side of one of the girders of the bridge, so that when the latter was deflected by the weight of the engine or train, either placed at rest or passing over it, the pencil traced the extent of the deflection upon a drawing-board attached to the scaffold. An engine and tender, which had been in each case liberally placed under our orders by the Directors of the Companies, was made to traverse the bridges at different velocities, or rest upon them at pleasure. The span of the Ewell Bridge is 48 feet, and the statical deflection due to the above load rather more than one-fifth of an inch. This was slightly but decidedly increased when the engine was made to pass over the bridge, and at a velocity of about 50 miles per hour an increase of one-seventh was observed. As it is known that the strain upon a girder is nearly proportional to the deflection, it must be inferred that in this case the velocity of the load enabled it to exercise the same pressure as if it had been increased by one-seventh, and placed at rest upon the centre of the bridge. The weight of the engine and tender was 39 tons, and the velocity enabled it to exercise a pressure upon the girder equal to a weight of about 45 tons. Similar results were obtained from the Godstone Bridge. We would take this opportunity of mentioning how much we are indebted to Mr. P. W. Barlow and to Mr. Hood for the assistance they afforded us in making these experiments.

We have also to express our obligations to the Astronomer Royal for the advantage of his presence during the above and other experiments, as well as for many valuable suggestions during the progress of the inquiry.

In addition to the above experiments, we have made many for the purpose of supplying data for completing the mechanical theory of elastic beams. If a beam be in any manner bent, its concave side will be compressed, and its convex side extended. An exact knowledge of

the laws which govern its compression and extension must precede any accurate general theory of its deflections, vibrations, and ruptures.

The law which is usually assumed in mathematical investigations, and by which the longitudinal compressions and extensions, within certain limits, are assumed to be directly proportional to the forces by which they are produced, although very nearly true in some bodies, is not, perhaps, accurately true for any material.

Experiments have, therefore, been made to determine with precision the direct longitudinal extension and compression of long bars of cast and wrought iron. The extensions were determined by attaching a bar, 50 feet in length and 1 inch square, to the roof of a lofty building, and suspending weights to its lower extremity.

The compressions were ascertained by inclosing a bar 10 feet long and 1 inch square in a groove, placed in a cast-iron frame, which allowed the bar to slide freely without friction, and yet permitted no lateral flexure. The bar was then compressed by means of a lever, loaded with various weights. Every possible precaution was taken to insure accuracy. The following formulæ were deduced for expressing the relation between the extension and compression of a bar of cast iron, 10 feet long and 1 inch square, and the weights producing them respectively:

$$\text{Extension,} \quad w = 116117\, e - 201905 e^2$$
$$\text{Compression,} \quad w = 107763\, d - 36318 d^2.$$

Where w is the weight in pounds acting upon the bar, e the extension, and d the compression in inches.

And the formulæ deduced from these, for a bar 1 inch square and of any length, are

$$\text{For Extension,} \quad w = 13934040\, \frac{e}{l} - 2907432000\, \frac{e^2}{l^2}.$$

$$\text{For Compression,} \quad w = 12931560\, \frac{d}{l} - 522979200\, \frac{d^2}{l^2}.$$

Where l is the length of the bar in inches.

These formulæ were obtained from the mean results of four kinds of cast iron.

For the further development of this research, we beg to refer to the Commissioners' Report, Appendix A*. The mean tensile strength of cast iron derived from these experiments is 15711 lbs. per square inch, and the ultimate extension $\frac{1}{600}$ of the length, and this weight would compress a bar of iron of the same section $\frac{1}{715}$ of its length. It must be observed that the usual law is very nearly true for wrought iron.

Many denominations of cast iron have got into common use, of

* Report of the Commissioners appointed to inquire into the Application of Iron to Railway Structures. 2 vols. folio, 1850.

which the properties had not yet been ascertained with due precision. Seventeen kinds of them have been selected, and their tensile and crushing forces determined. Experiments have also been made upon the transverse strength and resistance of bars of wrought and cast iron acted upon by horizontal as well as vertical forces. These experiments will be found to exhibit very fully the deflections and sets of cast iron and the defect of its elasticity.

The bars which were experimented upon by transverse pressure were of sections varying from 1 inch square to 3 inches square, and of various other sections, and the actual breaking-weights show that the strength of a bar 1 inch square should not be taken as the unit for calculating the strength of a larger casting of similar metal, although the practice of doing so has been a prevalent one; for it appears that the crystals in the portion of the bar which cools first are small and close, whilst the central portion of bars 2 inches square and 3 inches square, is composed of comparatively large crystals, and bars of 3 inches square in section planed down on all sides alike to $\frac{3}{4}$ of an inch square are found to be very weak to resist both transverse and crushing pressure. Hence it appears desirable, in seeking for a unit for the strength of iron of which a large casting is to be made, that the bar used should equal in thickness the thickest part of the proposed casting.

The performance of these various experiments has been greatly facilitated by the permission which was liberally granted to us by the Lords Commissioners of the Admiralty, to make use of Portsmouth Dockyard in carrying on our investigations, in addition to which, however, we found it necessary to hire for several months some premises in Lambeth. This was found requisite for the performance of those portions of the experimental inquiry which had been undertaken by Eaton Hodgkinson, Esq. Although we are aware that, to point out the labours of individual members of the Commission would be impossible, and that it may appear invidious to single out one for praise, we cannot resist the expression of our thanks to the above-named gentleman for the zeal and intelligence with which he has carried out the remarkable series of experiments which are detailed in the Appendix A to this Report*, and which constitute a large proportion of those which have been already described.

In addition, we have obtained, from many of the iron-masters, information respecting the various processes employed by them in the manufacture of their irons, and the effect of such processes upon the strength and properties of the material produced; and we have also made careful inquiries of civil engineers with respect to the qualities and mixtures of iron preferred by them for the large castings used in the construction of railway bridges, and to the respective properties of Hot-

* Commissioners' Report, &c. 2 vols. folio, 1850.

blast and Cold-blast iron; this investigation has been greatly facilitated by the liberality and candour with which these gentlemen have communicated to us the results of their experience.

As no map of the kingdom had been constructed representing the districts in which iron is found and worked, we applied to the officers of the Museum of Practical Geology for their assistance, and they caused one to be prepared expressly to accompany this Report, in which the principal furnaces now in blast are shown.

Great differences of opinion exist with respect to the best qualities and mixtures of iron, and, after all, it appears that those employed for large castings depend practically so much upon the commercial question of relative cost, that engineers are rarely able to select the very best material. It is generally admitted that engineers have no guarantee that the mixture for which they have stipulated in a contract shall be that used by the founder, and no certain test by which to determine whether a given piece of iron has been manufactured by hot blast or cold blast. A very good protection appears to be contained in the recommendation of Mr. Fox, that engineers, in contracting for a number of girders, should stipulate that they should not break with less than a certain weight (leaving the mixture to the founder), and cause one more than the required number to be cast. The engineer may then select one to be broken, and, if it break with less weight than that agreed upon, the whole may be rejected.

At the beginning of the railway system, the bridges were naturally constructed upon similar principles to those which had been already employed for common roads or aqueducts. Some of these ordinary constructions have proved inadequate to sustain the enormous loads and vibrations of railway trains. Some have been considered too expensive; others, as the suspension bridges, have been found wholly unfitted for railway purposes. Moreover, the necessity for preserving the level of a railroad as much as possible, combined with that of passing under or over existing canals, rivers, or roads, has created a demand for those forms of bridges which admit of being kept as low as possible, consistently with the proper headway or passage below; or, in other words, of making the least possible difference of level between the road or stream which the bridge has to carry and that which it has to cross.

From these causes, combined with the innumerable opportunities of building new bridges which the railways have given occasion to, and a constant endeavour to reduce the expense of building them, a variety of new constructions have been proposed and essayed, most of them of great merit and value, while others appear to be of very doubtful stability.

On the whole, the art of railway bridge-building cannot be said to be in that settled state which would enable an engineer to apply prin-

ciples with confidence. We have therefore thought it our duty to inquire into the present methods of railway bridge-building, to collect in evidence the opinions and practice of the leading members of the profession of civil engineers upon this branch of construction, and especially with respect to the form and proportions of simple cast-iron girders, the practical limits to the employment of such girders, the methods of combining them with the rest of the structure, the various forms of compound girders, the expediency of several combinations of wrought iron with cast iron, and, finally, the comparative merits of plain girders, and of other forms in which the principles of the arch, or other methods of giving stiffness, are introduced.

The simplest bridge, and that which admits of the greatest possible headway at a given elevation, is, undoubtedly, the straight girder bridge.

The length of a simple cast-iron girder appears to be limited only by the power of making sound castings, and the difficulty of moving large masses. Thus the practical length has been variously stated to us as 40, 50, and 60 feet. The form resulting from Mr. Hodgkinson's former experiments on this subject is universally admitted to be that which gives the greatest strength, but the requirements of construction compel many variations from it, especially in the ratio between the top and bottom flanges. Moreover, the convenience and the necessity of keeping the roadway for rails as low as possible has introduced a practice of supporting the beams which sustain the rails upon one side of the bottom flange. The pressure of the roadway and of the passing loads being thus thrown wholly on one side of the central vertical web of the girder produces torsion (which is not always taken into account in determining the proportions of the girder). The existence of this torsion is admitted on all hands, and various schemes are employed to counteract and diminish it; but the form of a girder that will effectually resist this disturbing force, without incurring other evils, still remains a desideratum.

The requisite length of girders is increased considerably by the excessive use of skew bridges, and it is much to be regretted that difficulties should often be thrown in the way of altering the course of existing roads and canals, when the line of a proposed railway happens to cross them at an acute angle. Partly from these causes, and partly from a little indulgence in the pride of construction, skew bridges may be found of which, from the obliquity of the bridge, the girders are more than double the length that would be required by the direct span of the opening to be crossed.

When the span of the opening or other circumstances render the use of single straight girders unadvisable, straight girders built up of several separate castings bolted together, and sometimes trussed with wrought-iron tension rods, are largely employed, and necessarily with great

varieties of construction. By these means the girders may be extended to spans of upwards of 120 feet.

When wrought iron is combined with cast iron in the manner of trussing, several difficulties arise from the different expansions of the two metals, and the difference of their masses, which causes the wrought-iron rods to be more rapidly affected by a sudden change of temperature than the cast-iron parts. The constant strain upon the wrought iron tends to produce a permanent elongation, and hence tension rods may require to be occasionally screwed up. We have sought for opinions and information upon all these questions, and these show that the greatest skill and caution is necessary to ensure the safe employment of such combinations. It is not admitted that the vibration of railway trains would loosen or injure the bolts or rivets of compound girders. Nevertheless wood, felt, or other similar substances, have occasionally been introduced between surfaces to diminish the communication of vibration.

The general opinion of engineers appears to be that the cast-iron arch is the best form for an iron bridge, when it can be selected without regard to expense, or to the height above the river or road which is to be crossed. For low bridges, the bowstring girder is also strongly recommended.

Lattice bridges appear to be of doubtful merit.

The latest mode of construction that has been introduced consists of boiler plates, riveted together as in iron ship-building, and combined in various ways with cast iron. Hollow girders are thus formed, which are either made so large as to admit of the road and carriages passing through them, as in the Conway and Britannia Bridges, or else these tube girders are made on a smaller scale, and employed in the same manner as the ordinary cast-iron girders, to sustain transverse joists which carry the road. The first kind is applicable to enormous spans, those of the two bridges above mentioned being 400 and 462 feet respectively. The second kind are said to be cheaper and more elastic than other forms for spans that exceed 40 feet. These methods appear to possess and to promise many advantages, but they are of such recent introduction that no experience has yet been acquired of their powers to resist the various actions of sudden changes of temperature, vibrations, and other causes of deterioration. We have thought it our duty to seek for information with respect to them, and we find engineers to be, for the most part, exceedingly favourable towards them; but, for the reasons above stated, we are unable to express any opinion upon them. At the same time, we desire to bear testimony to the patient care and scientific manner in which the forms and proportions of the great tubes of the Conway and Britannia Bridges have been elaborated; and we must beg to refer to the Minutes of Evidence, and to the papers con-

tained in the Appendix, for the details of the information which we have collected.

The investigation in which we have been concerned has made it evident that the novelty of the railway system has introduced a variety of new mechanical causes, the effects of which have not yet had time fully to develope themselves, on account of the extent and number of new railways, and the rapidity with which they were constructed, in many cases scarcely giving breathing time to the engineers by which to observe and profit by the experience of each successive new construction. Thus it has happened that some portions of mechanism and structure have been made too weak, or placed in unfavourable combinations; and hence some unavoidable, but most lamentable and sometimes fatal, accidents have been occasioned. It also appears that there exists a great want of uniformity in practice in many most important matters relating to railway engineering, which shows how imperfect and deficient it yet is in leading principles.

But we have also observed, throughout the present inquiry, that the engineers have been already warned by experience of the necessity for increasing the strength of bridges employed in railways; and of watching more narrowly their construction, so as to render them as strong as possible. Accordingly we have found that the original structure of all those bridges which had shown the least signs of weakness has been carefully altered and strengthened, so as to leave no apparent cause for apprehension; while in new bridges better and stronger combinations are adopted.

And, in conclusion, considering that the attention of engineers has been sufficiently awakened to the necessity of providing a superabundant strength in railway structures, and also, considering the great importance of leaving the genius of scientific men unfettered for the development of a subject as yet so novel and so rapidly progressive as the construction of railways, we are of opinion that any legislative enactment with respect to the forms and proportions of the iron structures employed therein would be highly inexpedient.

We would, however, direct attention to the general conclusions we have arrived at from our own experiments, and from the information supplied to us, namely,—

That it appears advisable for engineers, in contracting for castings, to stipulate for iron to bear a certain weight, instead of endeavouring to procure a specified mixture.

That, to calculate the strength of a particular iron for large castings, the bars used as a unit should be equal in thickness to the thickest part of the proposed casting.

That, as it has been shown that to resist the effects of reiterated flexure, iron should scarcely be allowed to suffer a deflection equal to

one-third of its ultimate deflection, and since the deflection produced by a given load is increased by the effects of percussion, it is advisable that the greatest load in railway bridges should in no case exceed one-sixth of the weight which would break the beam when laid on at rest in the centre.

That as it has appeared that the effect of velocity communicated to a load is to increase the deflection that it would produce if set at rest upon the bridge; also, that the dynamical increase in bridges of less than 40 feet in length is of sufficient importance to demand attention, and may even, for lengths of 20 feet, become more than one-half of the statical deflection at high velocities, but can be diminished by increasing the stiffness of the bridge; it is advisable that, for short bridges especially, the increased deflection should be calculated from the greatest load and highest velocity to which the bridge may be liable; and that a weight which would statically produce the same deflection should, in estimating the strength of the structure, be considered as the greatest load to which the bridge is subject. For the method of calculating this increased deflection we beg to refer to Appendix B*.

Lastly, the power of a beam to resist impact varies with the mass of the beam, the striking body being the same, and by increasing the inertia of the beam, without adding to its strength, the power to resist impact is within certain limits also increased. Hence it follows that weight is an important consideration in structures exposed to concussions.

Whilst, however, we lament that the limited means which have been placed at our disposal, and the great time required for such investigations, have compelled us to leave in an imperfect state, or even to neglect altogether, many interesting and important branches of experimental inquiry, we trust that the facts and opinions which we have been enabled to collect, will serve to illustrate the action which takes place under varying circumstances in iron railway bridges, and enable the engineer and mechanic to apply the metal with more confidence than heretofore.

(Signed) WROTTESLEY.
ROBERT WILLIS.
HENRY JAMES.
GEORGE RENNIE.
W. CUBITT.
EATON HODGKINSON.

Whitehall, 26th July, 1849.

DOUGLAS GALTON,
Lieut. Royal Engineers,
Secretary.

* Commissioners' Report, &c. 2 vols. folio, 1850.

ABSTRACTS of the leading RESULTS of EXPERIMENTS on CAST and WROUGHT IRON made by Her Majesty's Commissioners, under the direction and superintendence of EATON HODGKINSON, Esq.

FIRST ABSTRACT.

RESULTS of EXPERIMENTS to determine the ultimate Tensile and Compressive, or Crushing Forces, of various denominations of Cast Iron in common use; these qualities not having been previously obtained in the Irons tried.

Description of the Iron.	Tensile strength per square inch of section.	Height of specimen.	Crushing strength per square inch of section.	Ratio of the powers to resist tension and compression.	
	lbs. tons.	Inch.	lbs. tons.		Mean.
Low Moor Iron, No. 1	12694 = 5·667	¾ 1½	64534=28·809 56445=25·198	1 : 5·084 1 : 4·446	1 : 4·765
Low Moor Iron, No. 2	15458 = 6·901	¾ 1½	99525=44·430 92332=41·219	1 : 6·438 1 : 5·973	1 : 6·205
Clyde Iron, No. 1	16125 = 7·198	¾ 1½	92869=41·459 88741=39·616	1 : 5·759 1 : 5·503	1 : 5·631
Clyde Iron, No. 2	17807 = 7·949	¾ 1½	109992=49·103 102030=45·549	1 : 6·177 1 : 5·729	1 : 5·953
Clyde Iron, No. 3	23468 = 10·477	¾ 1½	107197=47·855 104881=46·821	1 : 4·568 1 : 4·469	1 : 4·518
Blaenavon Iron, No. 1	13938 = 6·222	¾ 1½	90860=40·562 80561=35·964	1 : 6·519 1 : 5·780	1 : 6·149
Blaenavon Iron, No. 2, first sample	16724 = 7·466	¾ 1½	117605=52·502 102408=45·717	1 : 7·032 1 : 6·123	1 : 6·577
Blaenavon Iron, No. 2, second sample	14291 = 6·380	¾ 1½	68559=30·606 68532=30·594	1 : 4·797 1 : 4·795	1 : 4·796
Calder Iron, No. 1	13735 = 6·131	¾ 1½	72193=32·229 75983=33·921	1 : 5·256 1 : 5·532	1 : 5·394
Coltness Iron, No. 3	15278 = 6·820	¾ 1½	100180=44·723 101831=45·460	1 : 6·557 1 : 6·665	1 : 6·611
Brymbo Iron, No. 1	14426 = 6·440	¾ 1½	74815=33·399 75678=33·784	1 : 5·186 1 : 5·246	1 : 5·216
Brymbo Iron, No. 3	15508 = 6·923	¾ 1½	76133=33·988 76958=34·356	1 : 4·909 1 : 4·963	1 : 4·936
Bowling Iron, No. 2	13511 = 6·032	¾ 1½	76132=33·987 73984=33·028	1 : 5·635 1 : 5·476	1 : 5·555
Ystalyfera anthracite Iron, No. 2	14511 = 6·478	¾ 1½	99926=44·610 95559=42·660	1 : 6·886 1 : 6·585	1 : 6·735
Ynisced wyn anthracite Iron, No. 1	13952 = 6·228	¾ 1½	83509=37·281 78659=35·115	1 : 5·985 1 : 5·638	1 : 5·811
Ynisced wyn anthracite Iron, No. 2	13348 = 5·959	¾ 1½	77124=34·430 75369=33·646	1 : 5·778 1 : 5·646	1 : 5·712
Mr. Morries Stirling's Iron, denominated second quality	25764 = 11·502	¾ 1½	125333=55·952 119457=53·329	1 : 4·865 1 : 4·637	1 : 4·751
Mr. Morries Stirling's Iron, denominated third quality	23461 = 10·474	¾ 1½	158653=70·827 129876=57·980	1 : 6·762 1 : 5·536	1 : 6·149

SECOND ABSTRACT.—COLLISIONS AND VIBRATIONS.

Power of Beams of Cast Iron to sustain long-continued Impact.

The effect of impact and vibration upon structures was a leading object of inquiry with the Commission; and the first series of experiments instituted upon this subject was to determine the power of beams to sustain impacts many times repeated. For this purpose 16 bars were cast, all from Blaenavon Iron, No. 2, and five at least of the 16 were found to be slightly defective at some place, where they gave way. Whether these small defects were more numerous than would be found in practice, it would be difficult to determine.

Six of the bars were each 15 feet long and 3 inches square, and placed on supports 13 feet 6 inches asunder; seven were each 10 feet long and 2 inches square, and 9 feet between the supports; and three were each 5 feet long, 1 inch square, and 4½ feet between the supports. Of these bars, six were bent through ⅓rd of their ultimate deflection at each blow, and five of them bore each 4000 blows without breaking; the sixth was broken at a flaw with 1085 blows. One large bar, bent by impact through $\frac{5}{12}$ths of its ultimate deflection, was broken at a defective place with 1350 blows.

Of six bars bent by blows through half their ultimate deflection, five were broken with less than 4000 blows each; one with 29; another with 127, &c. The only bar which bore the 4000 blows was one of the smallest kind, or 1 inch square.

Of three bars, one bent to $\frac{7}{12}$ths, and two to ⅔rds the ultimate deflection; all were broken: the two latter with 127 and 474 blows respectively; the former required 3700 blows to break it.

Of ten bars of Low Moor Iron, No. 2, each 10 feet long and 2 inches square, placed on supports 9 feet asunder, and struck in the middle with long-continued impact, as before, four broke at defective places, and two at sound ones. Three were subjected to impacts, bending them through ⅓rd of their ultimate deflections, and bore the test without fracture: of three bent by blows through half their ultimate deflection, two were broken; those bent through ⅔rds were all broken.

On the whole, it appears that no bar but one, and that a small one, stood 4000 blows, each bending it through half its ultimate deflection; but all the bars, when sound, stood that number of blows, each bending them through ⅓rd their ultimate deflection. It must, however, be borne in mind that a cast-iron bar will be bent to ⅓rd of its ultimate deflection with less than ⅓rd of its breaking-weight laid on gradually; and $\frac{1}{6}$th of the breaking-weight laid on at once would produce the same effect, if the weight of the bar was very small compared with the weight laid on it. Hence the prudence of always making beams capable of bearing more than six times the greatest weight which will be laid upon them.

For more information see the following Abstract:—

ABSTRACT OF THE LEADING RESULTS ON LONG-CONTINUED IMPACT.

TRANSVERSE STRENGTH to resist long-continued Impact from Balls striking *horizontally* against the middle of Bars, the Balls acting as Pendulums with a radius (r) of 17 feet 6 inches.

The bars were cast of three sizes, namely, 15 feet long and 3 inches square; 10 feet long and 2 inches square; and 5 feet long and 1 inch square. A thin piece of lead, varying from 2 lbs. to 4 lbs. weight, was generally attached to the side of the bar where struck, to prevent injury to its surface by the impact.

Sixteen Bars of Blaenavon Iron, No. 2.

Distance between the supports.	Side of square of bar nearly.	Weight of striking ball.	Assigned deflection in terms of ultimate deflection*.	Number of blows given to the bar.	Effect on bar.	REMARKS.
Feet. In.	Inches.	lbs.				
	3	151¼	⅓	1085	Broken ...	Slight defect in casting.
	3	151¼	⅓	4000	Not broken.	
13 6	3	603	⅓	4000	Not broken.	
	3	603	4/12	1350	Broken ...	The bar was somewhat defective at place of fracture.
	3	151¼	½	127	Broken.	
	3	603	½	3026	Broken.	
	2	75½	⅓	4000	Not broken.	
	2	603	⅓	4000	Not broken.	
	2	75½	½	29	Broken ...	Defective bar.
9 0	2	75½	½	1282	Broken ...	Slightly defective.
	2	603	½	3695	Broken ...	Slightly defective.
	2	75½	⅔	127	Broken.	
	2	603	⅔	474	Broken.	
	1	75½	⅓	4000	Not broken.	
4 6	1	75½	½	4000	Not broken.	
	1	75½	7/12	3700	Broken ...	Slightly defective.

* The ultimate deflection was obtained from the experiments on transverse pressure.

Ten Bars of Low Moor Iron, and one of a mixture of Wrought and Cast Iron.

These bars were cast to be 10 feet long and 2 inches square; they were placed on supports 9 feet asunder. The radius (r) of the pendulum was 17·208 feet when the weight of the striking ball was 603 lbs.; and 18·208 feet when the weight of the striking ball was 151¼ lbs.

Side of square of bar nearly.	Weight of striking ball.	Assigned deflection in terms of ultimate deflection.	Number of blows given to the bar.	Effect on bar.	REMARKS.
Inches.	lbs.				
2	603	⅓	4000	Not broken.	
2	603	⅓	4000	Not broken.	
2	603	½	608	Broken ...	Slightly defective on one side.
2	603	½	132	Broken ...	Rather defective on the convex side.
2	603	⅔	175	Broken.	
2	603	⅔	79	Broken ...	Slight defect, or discolouration on the convex side.
2	151¼	⅓	400	Not broken.	
2	151¼	½	400	Not broken.	
2	151¼	⅔	102	Broken ...	The bar broke about 8½ inches from the centre, where there was a defect on the convex side, ¼ inch area.
2	151¼	⅔	38	Broken.	
2	603	½	3720	Broken ...	Mixture of wrought and cast iron.

THIRD ABSTRACT.—SYNOPSIS of some of the PRINCIPAL RESULTS in the Transverse Pressure by Vertical Force, and Table VI. on long flexible Cast-iron Beams, together with the Breaking Weights and Ultimate De- all the Experiments of each class, and the number of those Experiments

Number of Table.	Number of experiments from which the results are derived.	Distance between the supports.	Dimension of bar in direction of impact.	Dimension of bar perpendicular to impact.	Weight of bar between the supports.	Weight of the striking ball, (rad. 17½ ft.) (*w*)	Ultimate deflection.	Ultimate chord of arc of impact.
		Ft. In.	Inches.	Inches.	lbs.	lbs.	Inches.	Inches.
I.	2	13 6	3·046	3·0355	377·925	603	4·69 4·875 from sound bar	76·5 79 from sound bar
II.	2	13 6	1·53	6·122	381·075	603	9+	78
III.	2	13 6	6·095	1·538	383·975	603	2·4 nearly	80
IV.	4	6 9	3·	3·	192·58	603	1·23	56·75
V.	2	6 9	1·49	6·095	186·575	603	2·4375	52·75
VI.	3 struck at the quarter span.	6 9	3·	3·	195·663	603	1·125	66·833
VII.	2	6 9	3·	3·	189·41	151¼	1·2656 and 1·3125 from the sound bar.	136·5 and 142· from the sound bar.
VIII.	4	9 0	2·012	1·983	108·08	603	3·125	39·9
IX.	3	9 0	1·979	2·02	108·15	151¼	2·67 and 2·75 from the sound bars.	79·08 and 80·5 from the sound bars.
X.	3	9 0	1·974	2·001	106·39	75⅛	2·833	124·
XI.	2 (2nd melting.)	9 0	1·9905	1·975	108·62	151¼	2·75	93·25
XII.	3	4 6	2·	2·	54·	603	·7812	29·3
XIII.	4	4 6	2·	2·	54·	75⅛	·892	98·5
XIV.	3	9 0	1·033	2·048	57·12	75⅛	5·00	85·
XV.	3	4 6	1·	2·	28·5	75⅛	.....	70·
XV.	3	4 6	2·	1·	28·5	75⅛	.....	71·67
XVI.	2	4 6	1·0675	1·0845	15·165	75⅛	1·68	52·5
XVII. Low Moor, No. 2.	4	9 0	1·984	2·002	105·79	151¼	2·81	84·4
XVIII. Mixture of iron from Warrington.	3	9 0	2·01	2·02	111·29	151¼	2·875	99·5
XIX. Mixture of iron, supposed to be Mr. Stirling's, called his second quality.	4	9 0	1·997	1·982	107·66	151¼	2·58	86·

19 Tables of Experiments on the effect of Horizontal Impacts upon flections of Beams of the same size, as obtained from Tables I. to VI. on Bars bent by Horizontal Pressure. The results set down are means from is given in Column 2.

Ultimate vertical descent of the ball (h).	Ultimate work done by the ball (w h).	Breaking-weight of similar bar, by transverse pressure applied horizontally.	Corresponding ultimate deflection by horizontal pressure.	Breaking-weight of similar bar, by transverse pressure applied vertically.	Corresponding ultimate deflection by vertical pressue.
Feet.		lbs. Mean.	Inches. Mean.	lbs.	Inches.
1·238	746·51	2865 } 2888 2912 }	4·939 } 4·76 4·59 }	2685 from 2 experiments, or 2863 previous to the reduction of the results to those of a bar 3 in. square.	4·6269 from 2 experiments, or 4·5505 previous to the reduction of the results.
1·2071	727·88	.....	.....	.....	.....
1·270	765·81	.....	.....	.....	.....
·6390	385·32	6207	1·311	6117 from 3 experiments, or 6440 from bars as cast, or previously to reduction of results.	1·2916 from 3 experiments, or 1·2722 from bars, results not reduced.
·5521	332·916	.....	.....	.....	.....
·8861	534·32	.....	.....	.....	.....
3·697 and 4·001 from the sound bar.	559·17 and 605·15 from the sound bar.	.....	.....	.....	.....
·3159	190·488	1274, 2 in. square exactly	2·981	1220 from 4 experiments.	2·854 from 4 experiments.
1·2408 and 1·2856 from the sound bars.	187·671 and 194·447 from the sound bars.	.....	.....	.....	.....
3·0506	230·32	.....	.....	.....	.....
1·7254	260·963	.....	.....	.....	.....
·1704	102·75	.....	.....	.....	.....
1·925	145·337	.....	.....	.....	.....
1·4334	108·223	468 from bars before reduction of results, 415 from bar reduced to exact size from 5 experiments.	5·954 6·227, reduced from 5 experiments.	.....	.....
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....
·5469	41·29	447	1·808	440 from 3 experiments.	1·779 from 3 experiments.
1·413	213·72	.....	.....	.....	.....
1·964	297·05	1539	3·495	1484 from 1 sound bar.	3·370
1·468	222·03	2230, result reduced for 2 in. square, from 4 experiments.	2·72	2174, result reduced for 2 in. from 4 experiments.	2·652, result reduced for 2 in. square, from 4 experiments.

Remarks on some of the leading Results in the foregoing Abstract.

1st. The bars in Tables I., II., and III. were of the same sectional area, length, and weight nearly, but differed in the form of their transverse section. They were placed on supports at the same distance (13½ feet) asunder, and struck horizontally by the same ball, 603 lbs. weight, suspended by a radius of 17 feet 6 inches. From the results it appears that the beam, 3 inches square, and the rectangular beams, 6 × 1½ inch section, struck on the broader and narrower sides respectively, had all very nearly the same strength to resist impact. These conclusions are drawn from a mean between two experiments in each case. In Table XV. six bars, each 2 × 1 inch section, and 5 feet long, were laid on supports 4½ feet asunder, and all struck by the same ball, 75½ lbs. weight, with arcs of a radius 17 feet 6 inches. Three of them were struck on the broader and three on the narrower sides, and their mean chords of impact to produce fracture were 70 inches and 71·67 inches respectively, or nearly the same, agreeing with the results of the experiments upon the former bars.

2nd. In Table IV. the bars were of the same dimensions in section as those in Table I., or 3 inches square, but the distance between the supports was reduced one-half. The resulting breaking deflection, 1·23 inch, was somewhat greater than one-fourth of that in Table I., or 4·875 inches, and the vertical descent to produce fracture was nearly one-half, but rather more, the depth fallen through in the two cases being ·639 inch and 1·238 inch. Comparing, in like manner, the half and whole bars in Tables V. and II., the depths are ·5521 inch and 1·2071 inch respectively. This result, coupled with the former one, shows that the depth fallen through to break the half bar is nearly half of that required to break the whole one. Comparing the results in Tables VIII. and XII., and also Tables X. and XIII., it appears also that a bar of half the length of another resists with nearly half the energy, but somewhat more.

3rd. The experiments in Tables I., II., III., IV., and V. afford illustrations of some of the conclusions in the large generalization of Dr. Young, deduced from neglecting the inertia of the beam. (*Nat. Phil., Lecture XIII.*) "The resilience of a prismatic beam, resisting a transverse impulse, follows a law very different from that which determines its strength, for it is simply proportional to the bulk or weight of the beam, whether it be shorter or longer, narrower or wider, shallower or deeper, solid or hollow. Thus, a beam 10 feet long will support but half as great a pressure without breaking as a beam of the same breadth and depth which is only 5 feet in length; but it will bear the impulse of a double weight striking against it with a given velocity, and will require that a given body should fall from a double height in order to break it."

4th. The experiments in Table VI. were made to compare the effects of striking a bar midway between the centre and one support with those of striking similar bars at the centre, as in Table IV. The great impacts, so near to the supports in these cases, would necessarily cause it to yield slightly, and thus increase the resisting powers of the bars to sustain impact. In experiments made by the author several years ago, given in the Fifth Report of the British Association, page 112, on bars 1 inch square, some subjected to impacts in the middle, and others at half the distance between the middle and one support; the chord of impact necessary to produce fracture was nearly equal in the two cases. The ratio of the deflections, from equal impacts at the middle and at one-fourth span, was nearly constant under different increasing degrees of impact; the deflections at the middle from equal impacts being to those at one-fourth span as 10 : 7 nearly. The relative ultimate deflections of the beam in the middle, and at a point half way between the middle and one end, ought to be as 10 : 7·5 nearly.

5th. The bars in Tables VIII., IX., and X. were all of the same iron and size, and the only difference was in the weights of the striking balls. The distances fallen through, and the work done by the balls to produce fracture, being respectively, ·3159 and 190·488 with the 603 lbs. ball; 1·2856 and 194·447 with the 151¼ lbs. ball; and 3·0506 and 230·32 with the 75½ lbs. ball, affording a good illustration of the resistance from the weight of the bar.

6th. The bars in Table XI. were of the same iron (Blaenavon No. 2) as the others, but remelted, to ascertain the effect of melting this iron a second time without mixture upon its power to bear impact. The strength to resist blows was increased, but the iron was harder and much more unsound than before. The work done by the ball to break the beam in each case was increased in the ratio of 261 to 194.

7th. The deflections in cast-iron beams were always found to be greater than in proportion to the velocity of impact; whilst in wrought iron they were nearly constant with impacts of very different velocities. This fact shows that there is a falling off in the elasticity of cast iron through impact, analogous to that through pressure. The difficulty of obtaining a satisfactory theory of the power of cast-iron beams to sustain impact is considerably increased by this falling off in elasticity; but it is hoped that the varied nature of these experiments will tend much to reduce it. (The note in page 4 of the Report of the Commissioners, 2 vols. folio, 1850, and the approximate formulæ for horizontal impact to which it relates, connecting pressure with impact, and based on the supposition of perfect elasticity, apply therefore only to small impacts upon *cast*-iron beams.) *

* See note (A) at end of Volume.

Fourth Abstract.—Abstract of Results on Vertical Impacts upon Loaded Beams of Cast Iron.

All of the beams were of the same weight and strength nearly. They were placed on supports at a constant distance asunder, and struck in the middle by the same ball, falling through different heights.

The object of the Experiments was to obtain the effect of additional loads spread uniformly over the beam, in increasing its power of bearing impacts from the same ball. The beams were of Blaenavon Iron No. 2, and cast to be 14 feet 6 inches long and 3 inches square.

Mean weight of beam . . . . . 410·7 lbs.
Mean weight of beam between supports . . . . 382 lbs. nearly.
Distance between supports . . . . . 13 ft. 6 in.
Weight of ball . . . . . 303 lbs.

Depth fallen through by ball before impact.	Velocity of impact.	Deflections of Beam when loaded uniformly between the Supports, with Weights in addition to its own Weight, as below.							
		Weight of beam . 376·765 lbs. Unloaded, and without lead.	Weight of beam . . 382·1 lbs. Lead at centre 4	Weight of beam . . 375·6 lbs. Additional weight in centre . . 28	Weight of beam . . . 387 lbs. Additional load 166 Sum of the two 553 Lead at centre 4	Weight of beam . . 385·8 lbs. Additional load . . 389·25 Sum . . . 775·05 Lead at centre . . 4	Weight of beam . . 387·2 lbs. Additional load . . 389·0 Sum . . . 776·2 No lead.	Weight of beam . . 378·8 lbs. Additional load . . 391·2 Sum . . . 770·0 Lead at centre 4	Weight of beam . . 382·65 lbs. Additional load . . 956·25 Sum . . . 1338·9 Lead at centre . . 4
Inches.	Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
9	6·946	1·99	.....	.....	.....	.....	.....	1·698	.....
12	8·0208	2·29	2·154	2·177	2·103	1·942	1·946	2·03	1·483
15	8·967	2·555	2·496	.....	.....	.....	.....	2·28	.....
18	9·823	2·79	2·585	2·689	2·775?	2·426	2·444	2·455	1·883
21	10·610	3·05	2·926	2·909	2·761?	.....	.....	2·66	.....
24	11·343	3·21	3·155	3·198	3·149	2·844	2·846	2·87	2·178
25½	11·692	3·33	.....	.....	.....	.....	.....	.....	.....
27	12·031	3·49	3·406	3·413	3·371	.....	.....	3·064	.....
30	12·682	Broke with 28½	3·588	3·639	3·613	3·185	3·185	3·215	2·454
31½	12·995	.....	3·745	.....	.....	.....	.....	.....	.....
33	13·301	.....	Broke.	3·804	3·814	.....	.....	3·36	.....
36	13·892	.....	.....	3·976	4·045	3·544	3·527	3·585	2·695
39	14·460	.....	.....	4·164	4·163	.....	.....	3·665	.....
42	15·005	.....	.....	Broke.	4·283	3·585?	3·786	3·82	2·968
45	15·532	.....	.....	.....	4·485	.....	.....	3·925	.....
48	16·042	.....	.....	.....	Broke.	Broke.	Broke.	4·128	3·176
54	17·015	.....	.....	.....	.....	.....	.....	4·24	3·338
60	17·935	.....	.....	.....	.....	.....	.....	4·516	Broke.
66	18·810	.....	.....	.....	.....	.....	.....	Broke.	.....

Whence we see that beams loaded in different degrees bore more than beams unloaded, as below.

Additional load on beam in lbs.	Height of fall necessary to break the beam.	Velocity of impact answering to that height.	Remarks.
	Inches.		
None	28½	...	The set from the impacts on these loaded beams was very great, but it did not appear to injure their strength more than in ordinary cases.
Lead, 4 lbs. weight in centre	33	13·301	
28 lbs. in centre; no lead	42	15·005	
166 lbs. spread over beam + 4 lbs lead in centre	48	16·042	
389½ lbs. spread over beam; 4 lbs. lead in centre	48	16·042	
389 lbs. spread over; no lead	48	16·042	
391·2 lbs. spread over; 4 lbs. lead in centre	66	18·810	
956½ lbs. spread over; 4 lbs. lead in centre	60	17·935	

By comparing the impacts and deflections in the Abstract above it will be seen that the deflections are always nearly as the square root of the height fallen through by the ball, or as the velocity of impact.

Fifth Abstract.

Synopsis of Experiments on the Extension and Compression of Cast Iron.

1st. The direct Longitudinal Extension of Round Rods or Bars, 50 feet long and 1 inch Area of Section nearly, of four kinds of Cast Iron, as mentioned below.

Number of Table in which the Experiment is described.	Name of Iron.	Number of Experiments.	Mean area of section.	Weights per square inch, laid on with their corresponding Extensions and Sets; the last, in each case, being the largest, where all were observed together.			Mean breaking-weight, per square inch of section.	Mean ultimate Extension.
				Weights.	Extensions.	Sets.		
			Inch.	lbs.	Inch.	Inch.		Inch.
I.	Low Moor Iron, No. 2	2	1·058	2117	·09500	·00345	16408 lbs.	1·085
				6352	·3115	·0250	= 7·325 tons.	or $\frac{1}{461}$rd of
				10586	·5740	·06425		the length.
				14821	·9147	·12775		
II.	Blaenavon Iron, No. 2	2	1·0685	2096	·09422	·00268	14675 lbs.	·9325
				6289	·3065	·01675	= 6·551 tons.	or $\frac{1}{536}$rd of
				10482	·5770	·0575		the length.
				13627	·8370	·11475		
III.	Gartsherrie Iron, No. 3	2	1·062	2109	·09225	·001+	16951 lbs.	1·167
				6328	·3117	·01450	= 7·567 tons.	or $\frac{1}{378}$th of
				10547	·5862	·0475		the length.
				14766	·9452	·11325		
				15820	1·0487	·13812		
IV.	Mixture of Iron, composed of Leeswood, No. 3, and Glengarnock, No. 3, in equal proportions.	3	1·063	2107	·0914	·00376	14812 lbs.	·8095
				6322	·2967	·01823	= 6·6125 tons.	or $\frac{1}{741}$st of
				10536	·5349	·04321		the length.
				12643	·6702	·06417		

In two of the bars the length, exclusive of the couplings, was 48 feet 3 inches, and the extensions and sets from them have been increased in the ratio of 50 to 48 25, to correspond to a length of 50 feet.

2nd. The Extension of Rods 10 feet long and 1 inch square, deduced from the preceding Experiments, and compared with observed Compressions of Bars of the same Irons and the same size, cast with them for comparison, together with Formulæ for computing the Weights from the Extensions and Compressions.

Extension, Table IX.						Compression, Table VI.					
Number of Experiments.	Weights laid on, with the corresponding Extensions and Sets.				Error in parts of the weight, when it is computed from the formula $w = 116117e - 201905e^2$.	Number of Experiments.	Mean Weights laid on, with corresponding Mean Compressions, Sets, and Ratios of Weights to Compressions.				Error in parts of the weight, when it is computed from the formula $w = 107763d - 36318d^2$.
	Weights (w).	Extensions (e).	Sets.	$\frac{w}{e}$.			Weights (w).	Compressions (d).	Sets.	$\frac{w}{d}$.	
9	1053·77	·0090	.....	117086	$-\frac{1}{33}$	8	2064·745	·01875	·00047	110120	$-\frac{1}{35}$
9	1580·65	·0137	·00022	115131	$-\frac{1}{57}$	8	4129·49	·03878	·00226	106485	$-\frac{1}{118}$
9	2107·54	·0186	·000545	113309	$-\frac{1}{119}$	8	6194·24	·05978	·00400	103617	$+\frac{1}{33}$
9	3161·31	·0287	·00107	110150	$+\frac{1}{640}$	8	8258·98	·07879	·00645	104823	$+\frac{1}{1230}$
9	4215·08	·0391	·00175	107803	$+\frac{1}{317}$	8	10323·73	·09944	·00847	103819	$+\frac{1}{378}$
9	5268·85	·0500	·00265	105377	$+\frac{1}{193}$	8	12388·48	·12030	·010875	102980	$+\frac{1}{526}$
9	6322·62	·0613	·00372	103142	$+\frac{1}{127}$	8	14453·22	·14163	·01405	102049	$+\frac{1}{779}$
9	7376·39	·0734	·00517	100496	$+\frac{1}{123}$	8	16517·97	·16338	·01712	101102	$+\frac{1}{1139}$
9	8430·16	·0859	·00664	98139	$+\frac{1}{143}$	8	18582·71	·18505	·02051	100420	$+\frac{1}{1671}$
9	9483·94	·0995	·00844	95316	$+\frac{1}{134}$	8	20647·46	·20624	·02484	100114	$+\frac{1}{2359}$
9	10537·71	·1136	·01062	92762	$+\frac{1}{231}$	8	24776·95	·24961	·08220	99263	$-\frac{1}{176}$
9	11591·48	·1283	·01306	90347	$-\frac{1}{674}$	8	28906·45	·29699	·04300	97331	$-\frac{1}{575}$
9	12645·25	·1448	·01609	87329	$-\frac{1}{195}$	7	33030·80	·35341	·06096	93463	$+\frac{1}{62}$
6	13699·83	·1668	·02097	82133	$+\frac{1}{333}$	7	37159·65	·41149	·08421		
4	14793·10	·1859	·02410	79576	$-\frac{1}{89}$						

Extension and Compression of Cast-Iron Bars.

The experiments to determine the effects of various weights to extend and compress bars of cast iron longitudinally were made upon four different kinds of that metal. From the mean results given in the preceding abstract of Table IX., on the extension of bars, and Table VI., on their compression, the following formulæ were deduced for expressing the relations between the extensions and compressions of a bar 10 feet long and 1 inch square, and the weights producing them respectively.

Extension:

$$w = 116117e - 201905e^2$$

Compression:

$$w = 107763d - 36318d^2.$$

Where w is the weight (in pounds) acting upon the bar, e the extension, and d the compression (in inches).

To express the relation between w and the corresponding extension and compression, when the length of the bar is reduced from 10 feet to

1 foot, we assume that the extension and compression are uniform throughout the length of the bar. Therefore, the extension or compression of one-tenth its length will be reduced in the ratio of 1 : 10. Consequently, in order that the value of w may remain unaltered in the formulæ, the co-efficients of e and d must be increased in the ratio of 10 : 1, and the co-efficients of e^2 and d^2 in the ratio of 10^2 : 1. These modifications being effected, the formulæ for a bar 1 foot long become

$$w = 1161170e - 20190500e^2 \text{ for extension,}$$
$$w = 1077630d - 3631800d^2 \text{ for compression.}$$

If the bars were 1 inch only in length, those to which the first formulæ applied would be reduced in length in the ratio of 1 : 120.

Consequently, the extensions and compressions would be reduced in the same ratio; and, in order that w might remain unaltered, the co-efficients of e and d must be increased in the ratio 120 : 1, and the co-efficients of e^2 and d^2 in the ratio of 120^2 : 1. These changes being made, the formulæ for bars 1 inch long and 1 inch square become

$$\begin{aligned} w &= 116117 \times 120e - 201905 \times 120^2 e^2 \\ &= 13934040e - 2907432000e^2 \text{ for extension,} \\ w &= 107763 \times 120d - 36318 \times 120^2 d^2 \\ &= 12931560d - 522979200d^2 \text{ for compression;} \end{aligned}$$

where, as before, w is expressed in pounds, d and e in inches.

Lastly, if the length of the bar be l inches, the corresponding formulæ for w may be deduced from those last given, by considering the bar to which those formulæ apply increased in length in the ratio l : 1. Consequently, as before, to adapt the formulæ to the present case, the co-efficients of e and d must be diminished in the ratio 1 : l, and the co-efficients of e^2 and d^2 in the ratio of 1 : l^2.

The formulæ for a bar 1 inch square and l inches in length are, therefore,

$$w = 13934040\frac{e}{l} - 2907432000\frac{e^2}{l^2} \text{ for extension . . . (A),}$$

$$w = 12931560\frac{d}{l} - 522979200\frac{d^2}{l^2} \text{ for compression . . (B).}$$

The mean tensile strength per square inch of section in the irons experimented upon was 15711 lbs. = 7·014 tons, and the mean ultimate extension for lengths of 10 feet was ·1997 inch, or $\frac{1}{5}$ inch nearly, being $\frac{1}{600}$th part of the length.

The mean compression of bars of the same metal and dimensions by the weight 15711 lbs. (the breaking-weight by extension, as above stated) was found from the experiments to be ·15488 inch, or $\frac{1}{775}$th part of the length.

To find the values of e and d in terms of w, in the preceding equations for cast iron :

In the general form of these equations,

$$w = ae - be^2$$

$$\text{whence } be^2 - ae = -w$$

$$e^2 - \frac{a}{b}e = -\frac{w}{b}$$

$$e^2 - \frac{a}{b}e + \frac{a^2}{4b^2} = \frac{a^2}{4b^2} - \frac{w}{b}$$

$$\therefore e = \frac{a}{2b} \mp \sqrt{\frac{a^2}{4b^2} - \frac{w}{b}} \quad \ldots \quad \text{(C)}.$$

Extension of a bar l inches long and 1 inch square in terms of the weight stretching it.

From equation (A) for elongation of bars of cast iron, we have, in equation (C),

$$a = \frac{13934040}{l}, \quad b = \frac{2907432000}{l^2},$$

substituting these values of a and b in (C), we have,

$$e = \frac{13934040}{5814864000} \times l \mp \sqrt{\left(\frac{13934040}{5814864000}\right)^2 l^2 - \frac{wl^2}{2907432000}}$$

$$= \cdot 00239628\, l \mp \sqrt{\cdot 00000574215\, l^2 - \cdot 000000000343946\, l^2 w^2}$$

$$\therefore e = l\{\cdot 00239628 - \sqrt{\cdot 00000574215 - \cdot 000000000343946\, w}\}, \text{ (D)},$$

where w is in lbs. and e in parts of an inch, the negative sign being that alone which is applicable in the quantity under the root.

If $l =$ 1, then the extension is that produced by a length of bar $=$ 1 in.
If $l =$ 12, " " " $=$ 1 ft.
If $l =$ 120, " " " $=$ 10 ft.

Example 1. Suppose $w = 11591 \cdot 48$, and $l = 10$ feet or 120 inches, then substituting for w and l their values in equation (D), we have,

$$e = l\{\cdot 00239628 - \sqrt{\cdot 00000574215 - \cdot 00000398684}\}$$

$$= l\{\cdot 00239628 - \cdot 00132488\} = 120 \times \cdot 0010714 = \cdot 128568 \text{ inch.}$$

Comparing this with the result in Table IX., on extension of bars, from the same pressure, 11591·48 lbs., we have a defect of $\frac{1}{470}$th, the real extension being ·1283 inch.

Example 2. Suppose $w = 2107 \cdot 54$ lbs., and $l = 10$ feet; substituting for w and l in equation (D), we have,

$$e = l\{\cdot 00239628 - \sqrt{\cdot 00000574215 - \cdot 00000072488}\}$$

$$= l(\cdot 00239628 - \cdot 00223993) = 120 \times \cdot 00015635 = \cdot 01876.$$

It should be ·0186, $\therefore$ error $= \frac{1}{115}$.

Compression of a bar l inches long and 1 in. square in terms of the weight producing it.

The relation between the weight and the compression being expressed by an equation of a similar form to that between the weight and the extension, or $w = ad - bd^2$, we obtain, in the same manner as before,

$$d = \frac{a}{2b} \mp \sqrt{\frac{a^2}{4b^2} - \frac{w}{b}};$$

substituting the values of a and b derived from the equation (B) for cast iron, or $\frac{12931560}{l}$ for a, and $\frac{522979200}{l^2}$ for b, we obtain

$$d = \frac{12931560}{1045958400} \times l \mp \sqrt{\left(\frac{12931560}{1045958400}\right)^2 l^2 - \frac{wl^2}{522179200}}$$

$$= l\{\cdot 012363359 - \sqrt{\cdot 000152853 - \cdot 00000000191212\, w}\} \quad . \quad . \quad (E)$$

Where w is in pounds and d in inches, the quantity under the root is affected by the negative sign, which alone is applicable in this instance.

Example 1. If $w = 8258{\cdot}98$ lbs., and the length 10 feet $= 120$ inches, we obtain, by substituting the value of w and l in equation (E),

$$d = l\{\cdot 012363359 - \sqrt{\cdot 000152853 - \cdot 00001579216}\}$$
$$= (\cdot 012363359 - \cdot 0117073)\, l = \cdot 07872 \text{ inch.}$$

Comparing this with the experimental result for this pressure in Table VI. on compression of bars, or ·07879, we find the deviation, or error, $= \frac{1}{1125}$ of the latter.

Example 2. If $w = 6194{\cdot}24$ lbs., and $l = 120$ inches, as before,

$$d = l\{\cdot 012363359 - \sqrt{\cdot 000152853 - \cdot 0000118441}\}$$
$$= l(\cdot 0004890) = \cdot 05868 \text{ inch.}$$
$$\text{It should be } \cdot 05978, \therefore \text{ error} = \tfrac{1}{54}\text{th.}$$

The first Example is the case of least deviation of the formula from the results of experiments in Table VI.; and the second is that of greatest deviation for pressures between 2 and 14 tons per square inch, the range between which the results are most trustworthy.

Example 3. If $w = 15711$ lbs., (the weight which would tear asunder an inch bar of these irons,) to find the compression of a bar 10 feet long and 1 inch square for the same weight.

Substituting in Equation (E) the values of w and l

$$d = l\{\cdot 012363359 - \sqrt{\cdot 000152853 - \cdot 00000000191212\, w}\}$$
$$= l(\cdot 012363359 - \cdot 0110820) = l(\cdot 0012813) = \cdot 15376 \text{ inch.}$$

The decrement, as obtained from the results of experiment in Table VI., on compression of bars, was ·15488 inch.

EXTENSION.

(Computed from the formula obtained.)

Weight.	Computed Extension.	Real Extension.	Error in parts of Real Extension.
1053·77	·00922	·0090	$+\frac{1}{41}$
2107·54	·01876	·0186	$+\frac{1}{116}$
4215·08	·03893	·0391	$-\frac{1}{355}$
6322·62	·06090	·0613	$-\frac{1}{163}$
8430·16	·08523	·0859	$-\frac{1}{138}$
10537·71	·11293	·1136	$-\frac{1}{170}$
12645·25	·14593	·1448	$+\frac{1}{138}$
14793·10	·19051	·1859	$+\frac{1}{40}$

COMPRESSION.

Weight.	Computed Decrement.	Real Decrement.	Error in parts of Real Decrement.
2064·745	·01928	·01875	$+\frac{1}{35}$
6194·24	·05863	·05978	$-\frac{1}{52}$
10323·73	·09909	·09944	$-\frac{1}{284}$
14453·22	·14077	·14163	$-\frac{1}{163}$
18582·71	·18379	·18505	$-\frac{1}{147}$
24776·95	·25114	·24961	$+\frac{1}{163}$
33030·80	·34705	·35341	$-\frac{1}{55}$

Transverse Flexure.

When a beam is bent in any degree the fibres or particles on the convex side are extended, and those on the concave side are compressed; and there is a line within the beam, intermediate between the two sides, in any transverse section where the particles are neither extended nor compressed. This is called the neutral line, and the particles on each side of it are stretched or compressed according to their distance from it; but the *force* exerted by those particles is not in proportion to the distance, in cast iron, at least, which we are treating of. It varies as a function composed of the 1st and 2nd powers of the distance nearly.

Thus, in the longitudinal extensions and compressions of a bar one inch area of section and l inches long, we have from the mean results of experiments on four kinds of cast iron, Equations (A) and (B),

$$w = 13934040\,\frac{e}{l} - 2907432000\,\frac{e^2}{l^2},$$

$$w = 12931560\,\frac{d}{l} - 522979200\,\frac{d^2}{l^2},$$

where w is the weight in lbs. producing the extension e or compression d in inches.

To apply this to transverse pressure, suppose the extension e and compression d of a small length of the material at a distance l from the neutral line to be represented by ml, $m'l$, respectively, then the extension and compression at any other distance x of a portion of the material originally of the same length will be mx and $m'x$, and the formula will become

$$w' = 13934040\,\frac{mx}{l} - 2907432000\,\frac{(mx)^2}{l^2}, \quad . \ . \ . \quad (F)$$

$$w'' = 12931560\,\frac{m'x}{l} - 522979200\,\frac{(m'x)^2}{l^2}, \quad . \ . \ . \quad (G)$$

where w', w'' are the forces of tension and compression exerted by the fibres at a distance x from the neutral line, and m, m', co-efficients dependent on them.

In the "Experimental Researches on the Strength of Iron," published by the author, and forming an additional volume to "Tredgold on Cast Iron," an attempt was made (pages 483–494) to give a more general computation of the strength of beams than had hitherto been done, the solution depending upon the supposition that the resistance of the particles to tension and compression varied in terms of the 1st and some other constant power of the extension and compression. Thus if x be the distance from the neutral line—

$$\varphi\,(x) = x - \frac{x^v}{na} = x - \frac{x^2}{na}, \text{ if } v = 2 \quad . \ . \ . \quad (I),$$

$$\varphi'\,(x') = x' - \frac{x'^{v'}}{n'a} = x' - \frac{x'^2}{n'a}, \text{ if } v' = 2 \quad . \ . \ . \quad (K),$$

where $\varphi\,(x)$ and $\varphi'\,(x')$ would be quantities respectively proportional to the forces of extension and compression of a particle at a distance x from the neutral line, n, n' quantities supposed to be constant.

From the experiments given in this inquiry it appears that v, v' are equal to 2; and in the Equations (J) and (K) a is the same quantity as l in Equations (F) and (G), $a = l$; and to adapt the formulæ (F), (G), for cast iron, found before, to the forms above, we have

$$\frac{w'l}{13934040\,m} = x - \frac{2907432000\,m^2l}{13934040\,ml^2} \times x^2$$

$$= x - \frac{2907432000\,m}{13934040} \times \frac{x^2}{l}, \text{ for extension} \quad . \ . \ . \ . \quad (L).$$

In like manner

$$\frac{w''l}{12931560\,m} = x - \frac{522979200\,m'}{12931560} \times \frac{x^2}{l}, \text{ for compression} \quad . \ . \quad (M).$$

Whence we obtain the values of n, n' in Equations (J), (K),

$$n = \frac{13934040}{2907432000\,m}, \quad n' = \frac{12931560}{522979200\,m'}.$$

By inserting these values in the formulæ given in the work referred to (pages 488 and 493), the position of the neutral line and the strength of a cast-iron beam of the form considered may be found.

Sixth Abstract.

Abstract of Results on the Transverse Strength of Cast-Iron Bars of different sizes, but mathematically similar, or relatively proportional in all their dimensions.

The bars were of Blaenavon iron, No. 2, and were respectively cast to be 1, 2, and 3 inches square, and 5, 10, and 15 feet long. They were placed on supports 4½, 9, and 13½ feet asunder, and the strength and ultimate deflections of the bars, when reduced to their exact size, were as below:

	Vertical Pressures.				Horizontal Pressures, computed from the Vertical Pressures.			
	Strength.		Ultimate Deflection.		Strength.		Ultimate Deflection.	
	lbs.	Mean.	Inches.	Mean.	lbs.	Mean.	Inches.	Mean.
Bars 4½ feet span and 1 inch square	461	440	1·796	1·779	468	447	1·823	1·808
	437		1·850		444		1·880	
	423		1·6917		430		1·720	
Bars 9 feet span and 2 inches square	1249	1338	2·996	3·0035	1303	1394	3·032	3·126
	1414		3·486		1469		3·622	
	1121		2·527		1175		2·649	
	1097		2·498		1151		2·621	
	1552*a*		3·620		1616		3·746	
	1594*b*		2·984		1648		3·085	
Bars 13½ feet span and 3 inches square	2698	2861	4·863	4·667	2877	3043	5·186	4·966
	2671		4·3908		2854		4·692	
	3389*c*		5·024		3573		5·297	
	2686*d*		4·891		2869		4·690	
Bars 6½ feet span and 3 inches square	6341	6117	1·3319	1·2916	6431	6207	1·351	1·311
	5795		1·190		5885		1·208	
	6215		1·353		6306		1·373	

The results marked with the letters *a*, *b*, *c*, *d*, are from bars which had been previously subjected to 4000 impacts, each bending them through ⅓rd of their ultimate deflections.

The strengths of similar bars, 1, 2, 3 inches square, and 4½, 9, and 13½ feet between the supports, are respectively 447, 1394, and 3043 lbs., to resist an horizontal pressure.

If the elasticity of the beams had been perfect, their strengths should have been as the square of their lineal dimensions, or as 1, 4, 9. Divid-

ing, therefore, the strengths as above by these squares, the quotients ought, on this supposition, to be equal. We have, however,

From the smallest bars . . . $\frac{447}{1} = 447$,

From the next larger bars . . $\frac{1394}{4} = 349$,

From the largest bars . . . $\frac{3043}{9} = 338$.

The quotients are unequal; but we see that the deviation from theory, on the supposition of perfect elasticity, is much greater in the smaller than in the larger bars, and that the strength of the smallest bar is greatly above that derived from the others, partly, it is probable, arising from defect of elasticity, but principally from the superior hardness of the smaller castings.

The ultimate deflections of similar elastic bars from horizontal pressure are as the lineal dimensions of the bars, nearly; and, therefore, similar bars, 1, 2, and 3 inches square, ought to deflect before fracture in those proportions. The ultimate deflections from experiments, as above, are below.

In bars 1 inch square	1·808
„ 2 inches square	3·126
„ 3 „	4·966

The deviation in the ultimate deflection of the bars, from 1, 2, 3, the ratio of their size, is therefore larger in the smallest (hardest) bars than in the others.

In Tables V. and IX., on the transverse strength of bars of wrought and cast iron mixed, (pages 82, 83, 90, 91,) we find a similar falling off to that above in the strength of the larger bars below that of the smaller ones, as is shown in the following extracts:—

	Strength to bear Horisontal Pressure.	Ultimate Deflection from Horisontal Pressure.
	lbs.	Inches.
Bars 9 feet span and 2 inches square	2230 from 4 experiments on the 1st sample .	2·720
	1545 from 2 experiments on the 2nd sample .	2·258
Bars 4½ feet span 1 inch square	630 from 4 experiments on the 1st sample .	1·4995
	505 from 4 experiments on the 2nd sample .	1·320

General Remarks.

On the Rapidity of Increase of Transverse Strength of Square Bars for Small Increments of their Sectional Dimensions.

The rapidity with which the transverse strength of square bars increases for small increments of their sectional dimensions does not

appear to have been always adequately considered in experimental inquiries. For square bars of constant length between the supports the transverse strength varies as the cube of the side of the square; consequently, for bars not greatly exceeding 1 inch square—such as have most frequently been subjected to series of experiments—an error of 1-10th of an inch (for example) in the sectional dimensions will produce an error of nearly one-third in estimating the transverse strength. It is, however, by no means unusual to assume bars, cast to be 1 inch square, to have exactly their nominal dimensions: variations of the actual dimensions, sometimes approaching to, or even exceeding, 1-10th of an inch, being neglected.

This source of error has been avoided in the present series of experiments—and in nearly all others by the author—by measuring the transverse dimensions of each bar to thousandths of an inch, and reducing the results by theory to those for the intended size of the casting. The nature and extent of the error will be easily seen by the following Table, in which is exhibited the difference of strength of square bars, of which the transverse dimension increases by hundredths of an inch. The breaking weight of the bar 1 inch square is taken at 448 lbs. (from the mean of experiments on cast iron). It will be observed, from this Table, that an error of less than 1-12th of an inch in the measure of the side of the square bar produces an error of one-fourth of the strength. A similar error of 1-10th of an inch produces an error of one-third the strength, and an error of less than 1-7th of an inch produces an error of one-half the strength.

COMPARATIVE TRANSVERSE STRENGTH of BARS of SECTIONS slightly differing from 1 square inch.

Side of Square of Bar.	Cube of Side.	Strength, or Breaking-Weight.	Approximate Error from assuming the Bar as 1 inch square.
Inch.	Inch.	lbs.	
1·00	1·000	448	...
1·01	1·0303	462	$\frac{1}{33}$
1·02	1·0612	475	$\frac{1}{17}$
1·03	1·0927	489	$\frac{1}{11}$
1·04	1·1249	504	$\frac{1}{8}$
1·05	1·1576	519	$\frac{1}{6}$
1·06	1·1910	534	$\frac{1}{5}$
1·07	1·2250	549	$\frac{1}{13}$
1·08	1·2597	564	$\frac{1}{4}$
1·09	1·2950	580	$\frac{1}{17}$
1·10	1·3310	596	$\frac{1}{3}$
1·11	1·3676	613	$\frac{12}{37}$
1·12	1·4049	629	$\frac{2}{3}$
1·13	1·4429	646	$\frac{12}{25}$
1·14	1·4815	664	$\frac{1}{2}$
1·15	1·5209	681	$\frac{12}{13}$

EXPERIMENTAL INQUIRIES to determine the Strength of Wrought-Iron Tubes, made at the instance of ROBERT STEPHENSON, Esq., M.P., F.R.S., to supply data for the erection of his Tubular Bridges across the Menai Straits and the River Conway. By EATON HODGKINSON, Esq., F.R.S., &c. &c.

THE introduction of wrought-iron riveted tubes for bridges is a new feature in engineering. It originated with one of our boldest, most skilful, and most successful engineers, who was driven to adopt it as a matter of necessity in one of the most stupendous structures of modern times. As engineer of the Chester and Holyhead Railway, Mr. Stephenson had to pass through portions of Penmaen Mawr, the splintery rock of which threatened to let down upon this new line the former Holyhead Road, which overhangs it.

He had to build enormous sea-walls, to prevent the encroachment of that element upon his railroad, which runs between the sea and the mountain.

In other parts of the line, too, on his way to Bangor, and beyond it, he had to raise extensive viaducts and pass through mountains presenting various obstacles; but the chief difficulty of all, and one sufficiently appalling to the stoutest-hearted engineer, was that of making across the Menai Straits a bridge, flat at the bottom, and rigid enough to support railway trains with very small flexure. At the point chosen the length of the whole bridge is 1350 feet or thereabouts; but the fortunate circumstance of a rock in the middle of the stream, called the Britannia Rock, causes the entire width of the water there, 900 feet or upwards, to be divided into two spans of 450 feet or 460 feet each. These distances were required to be kept open through their whole length, so that vessels of large size could pass everywhere under the bridge, the bottom part of which was to be 100 feet, at least, above high-water mark. These rigorous requirements rendered the use of the arch impracticable; and the Catenarian chain, which had been employed with such signal success by Telford in the stupendous bridge in the neighbourhood, was too flexible in its nature to be employed in the present instance, where, instead of single carriages, heavy trains and steam-engines would have to pass. To obviate these difficulties, Mr. Stephenson, by an effort of an original and master mind, conceived the bold idea of constructing an immense wrought-iron tube, formed of plates, riveted together, and sufficiently large to allow railway trains to pass through it. It was designed to reach from side to side, spanning the whole stream, and resting at intervals of 450 feet asunder, upon the piers erected to support it; to hang, as it were, between sea and sky, whilst the heaviest railway trains shot

like arrows through it. This magnificent idea presupposed a knowledge of the properties of wrought iron in directions to which the researches of engineers had not led them; though I hope I may presume that my own former researches, and those published by Mr. Fairbairn, in the preparation of which I had a large share, have, in some degree, paved the way to the success of the project. In order to acquire the requisite data for this extraordinary undertaking, Mr. Stephenson applied first to Mr. Fairbairn, and subsequently, through him, to myself; but I had been consulted privately on the matter from the commencement, or nearly so. In the first instance I was requested to assist in some experiments making in 1845, at Mr. Fairbairn's works, Millwall, Poplar, to obtain the strengths of small cylindrical and other tubes of wrought iron to resist a transverse strain. When these experiments were concluded, I gave, as requested by Mr. Stephenson, formulæ for the strength of tubes of these forms, taking the constants in the formulæ from the results of the experiments.

These formulæ were embodied in a report, which I drew up respecting the projected bridge, and which, with another report by Mr. Fairbairn, was printed, and presented to the Directors by Mr. Stephenson, with his own report upon the two, and upon the project in general.

The tubes above mentioned were, during the experiments, placed with their ends upon supports, and were loaded with weights suspended from the middle. Some of them were broken by the plates being torn asunder at the bottom; but many by the top plates, which are subjected to compression, becoming wrinkled.

This tendency to undulation in compressed plates presented a difficulty which had not previously been felt, and of which theory could offer no solution. The uncertainty whether a tube would break by compression or by tension prevented all reliance on theory, as it was evident that the tube would fail by corrugation of the compressed surface unless its weakness to sustain tension was greater than to sustain compression. As the laws of resistance of plates to wrinkling were utterly unknown, and if they had been known would probably, as I then thought, have been too complex to be useful in the prosecution of the present inquiry, it appeared best to devise means of stiffening the top in such a manner as to offer, without wrinkling, an adequate resistance, with the least quantity of material. To effect this, I suggested to Mr. Fairbairn the employment of long cylindrical tubes, to form the top of the larger tubes subjected to experiment. I repeated this suggestion in the presence of engineers and others assisting in the experiments. To meet this idea in part, Mr. Fairbairn had a tube made, with a top of iron, corrugated, or wrinkled longitudinally; and this answered moderately well, its resistance to transverse undulations, the difficulty complained of, being considerably increased.

In these preliminary experiments, which were on too small a scale to be useful as models of the intended bridge, even if the form of any of the tubes had been sufficiently good, it was not necessary to introduce tubes to stiffen the top part and prevent its failure by wrinkling. Plates sufficiently thick could easily be procured, and it is only where plates of sufficient thickness cannot be obtained that the introduction of small tubes into the top of the larger one is indispensable, or even desirable.

The obtaining of a proper proportion between the thickness of the plates at the top and bottom of the tubes is only to be determined by experiment. It may be that the thickness of either the top or bottom of the tube is much too great. If the thickness of the top is too small, then it becomes wrinkled and fails before the bottom. This indicates that the plates of the top require to be made thicker, and the tube may, with a a small addition of metal, be made to bear considerably more.

Many instances of this kind occurred in my experiments following, as in a tube with equal top and bottom plates, $\frac{1}{8}$ inch thick, which failed by wrinkling with 5·54 tons; and an increase of the thickness of the top plates, from $\frac{1}{8}$ to $\frac{3}{8}$ inch, for a small distance in the middle, raised the strength to 10·94 tons. In another tube, $\frac{1}{4}$ inch thick throughout, the strength was 22·8 tons; and a plate $\frac{1}{8}$ inch thicker, attached to the top in the middle, raised it to 32·5 tons. (See Table I.)

The formulæ which I investigated for the strength of tubes of three forms of section, tried in those preliminary experiments, are here given, and the results are taken from my report previously alluded to.

Cylindrical Tubes, or Tubes uniform throughout, but having their Section a Cylinder.

The strength of a cylindrical tube, supported at the ends and loaded in the middle, is expressed by the formula,

$$w = \frac{\pi f}{l a}(a^4 - a'^4);$$

where l is the distance between the supports; $a\,a'$ the external and internal radii; w the breaking weight; f the strain upon a unit of section, as a square inch, at the top and bottom of the tube, in consequence of the weight w; $\pi = 3{\cdot}14159$.

From this formula we obtain

$$f = \frac{w\,l\,a}{\pi\,(a^4 - a'^4)}.$$

As the value of f depends upon the quality of the material, and ought to be nearly constant in tubes of the same nature, as in wrought iron, it may be useful to give the value of f from each of the experiments in

Mr. Fairbairn's report. In doing this it will be necessary to explain that the value of w includes, besides the weight laid on at the time of fracture, the pressure from the weight of the tube between the supports, this last being equal to half that weight.

Computing the results, and taking the dimensions in inches, we obtain—

		lbs.	
Experiment	1.	$f = 33456$	
„	2.	$f = 33426$	
„	3.	$f = 35462$	
„	4.	$f = 32415$	Mean.
„	5.	$f = 30078$	lbs. tons.
„	6.	$f = 33869$	29887 = 13·34.
„	7.	$f = 22528$	
„	8.	$f = 22655$	
„	9.	$f = 25095$	

Fracture took place in all cases, either by the tube failing at the top, as before described, or tearing across at the rivet-holes. This happened on the average, as appears from the mean result, when the metal was strained to 13⅓ tons per square inch, or little more than half its full tensile strength.

That these tubes should yield at the bottom, under a strain of half that necessary to tear asunder the plates, is a consequence of the weakness of riveting; for, in some experiments which I made for Mr. Fairbairn several years ago, and read an account of at the Glasgow meeting of the British Association, it was shown that the strength of the plates, however riveted together with one row of rivets, was reduced to about one-half the tensile strength of the plates themselves; and if the rivets were somewhat increased in number, and disposed alternately in two rows, the strength was increased from ½ to ⅔ or ¾ at the utmost.

Elliptical Tubes.

The strength of these is expressed by the formula,

$$w = \frac{\pi f (b a^3 - b' a'^3)}{l a},$$

where a, a' are the semi-transverse external and internal diameters; b, b', the semi-conjugate external and internal diameters, the transverse axis being vertical, and the rest as before, w including in all cases the pressure from the weight of the tube. We have, therefore,

$$f = \frac{w l a}{\pi (b a^3 - b' a'^3)},$$

and from the experiments on tubes, of which the section was an ellipse, we have,

lbs.

In Experiment 20. $f = 36938$
„ 21. $f = 29144$
„ 24. $f = 45185$

Mean.
37089 lbs. = 16·55 tons.

Rectangular Tubes.

The transverse strength of tubes, of which the section is a rectangle, and the thickness of the plates at the top and bottom equal, the sides being of any thickness at pleasure, is expressed by the following formula:

$$w = \frac{2f(b\,d^3 - b'\,d'^3)}{3\,l\,d},$$

where d, d', are the external and internal depths respectively; b, b', the external and internal breadths; and the rest as before.

Whence,

$$f = \frac{3\,w\,l\,d}{2\,(b\,d^3 - b'\,d'^3)}.$$

The value of f, obtained from experiment No. 14 of Mr. Fairbairn, is 18495 lbs. = 8·2566 tons.

This is much below what was deduced from experiments on rectangular tubes, made by myself at the time, and detailed in Table I., an abstract of which was inserted in my report, and will be given further on.

The value of f, which represents the strain upon the top or bottom of the tube when it gives way, is the quantity per square inch which the material will bear before it becomes either crushed at the top side, or torn asunder at the bottom.

But it has been mentioned that thin sheets of wrought iron take a corrugated form, with a much less pressure than would be required to tear them asunder; and therefore the value of f, as obtained from the preceding experiments, is generally the resistance of the material to corrugation, or wrinkling, and would have been so in every instance if the plates had not been rendered weaker by riveting.

These experiments were made with two objects:—

1st. To ascertain how far the value of f would be affected by changing the thickness of the metal, the other dimensions of the tube remaining the same.

2nd. To obtain the relative strengths of similar tubes, proportionately greater or less in all their dimensions.

ABSTRACT of the EXPERIMENTS, as given in the Report, and detailed in Table I.

Length of Tube.	Weight of Tube.	Distance between Supports.	Depth of Tube.	Breadth of Tube.	Thickness of Plates of Tube.	Last Observed Deflection.	Corresponding Weight.	Breaking Weight.	Value of f for Crushing Strain.
Ft. In.	Cwt. Qrs.	Ft. In.	Inches.	Inches.	Inch.	Inches.	Tons.	Tons.	Tons.
31 6	44 3	30 0	24 nearly.	16 nearly.	·525	3·03	56·3	57·5	19·17
31 6	24 1	30 0	24 „	16 „	·272	1·53	20·3	22·75	14·47
31 6	10 1	30 0	24 „	16 „	·124	1·20	5·04	5·53	7·74
	Lbs. Oz.						Lbs.	Lbs.	
8 2	78 13	7 6	6 „	4 „	·132	·66	9416	9976	23·17
8 2	38 11	7 6	6 „	4 „	·065	·32	2696	3156	15·31
8 2	.....	7 6	6 „	4 „	.....	.....	.....	.....	.....
4 2½	10 12	3 9	3 „	2 „	·061	·435	2464	2464	24·56
4 3¼	4 15	3 9	3 „	2 „	·03	·13	560	672	13·42

These tubes were made without joints in the middle, to remove the anomalies caused by riveting: the value of f will be increased by that circumstance in the tubes with thicker plates.

Looking at the breaking weights of the tubes varying only in thickness we find a great falling off in the strength of the thinner ones; and the values of f show that in these—the thickness of the plates being ·525, ·272, and ·124 inch—the resistance per square inch will be 19·17, 14·47, and 7·74 tons, respectively. The breaking weights here employed do not include the pressure from the weight of the tube.

The value of f is usually constant in questions on the strength of bodies of the same nature, and represents the tensile strength of the material; but it appears from these experiments, that it is variable in tubes, and represents their power to resist crippling. It depends upon the thickness of the matter in the tubes when the depth or diameter is the same, or upon the thickness, divided by the depth, when that varies. The determination of the value of f, which can only be obtained by experiment, forms the chief obstacle to obtaining a formula for the strength of tubes of every form.

When f is known, the rest appears to depend upon received principles, and the computation of the strength may be made, as in the "Application de la Mécanique," of Navier, Part 1st, Article IV.; in the "Mechanical Principles of Engineering and Architecture," by Professor Moseley; or, as in papers of my own in the "Memoirs of the Literary and Philosophical Society of Manchester," Vols. IV. and V., Second Series.

The difficulty complained of above might be obviated by increasing the top of the tube in such a degree that its resistance to corrugation would be greater than to tension, but the quantity with which the top must be increased would be subject to laws to be determined by future experiments; and when the exact size was known for one thickness of

tube, another in proportion would be required for a different thickness of tube.

The uncertainty as to the way in which a tube, bent transversely, would break, rendered all dependence upon theory uncertain, in the then actual state of our experimental knowledge. I therefore represented to Mr. Stephenson, 10th March, 1846, the insufficiency of the former experiments made in London, and the necessity of others of a much larger kind, and adapted to supply various wants which I pointed out; and having obtained that gentleman's consent for me to make a large number of experiments, and to investigate fully the properties of such tubes as that intended to cross the Menai Straits, and to throw such light as I should be enabled by them to do, upon the form most desirable to be used, I had an apparatus of a very superior kind constructed, and made several classes of experiments in Manchester, in addition to those in Table I., of which an abstract had previously been given in the report.

The experiments were directed principally to the following objects:—

1st. To ascertain how far this value of f would be affected by changing the thickness of the metal, the other dimensions of the tube being the same. (For this, see last Abstract.)

2nd. To obtain the strength of tubes, precisely similar to others fixed on, but proportionately greater or less than the former, in all their dimensions, as length, breadth, depth, and thickness, in order to reduce to certainty computations as to the strength of tubes, mathematically similar in dimensions, but varying in actual size. (1st Supplement to Table I. and Table VII.)

3rd. To seek for the strength of tubes of different forms of section in the middle, and to furnish means of judging of the proper proportion of the metal in the top, bottom, and sides of the Menai tube. (Table VII., and elsewhere.)

4th. To ascertain the relative strength of uniform tubes to bear a weight in all parts of their length; and whether tubes, tapering in thickness from the middle towards the ends, according to theory, would be equally strong in every part. (2nd Supplement to Table I. and Table II.)

5th. To obtain the resistance of the tubes, previously tried *vertically*, to bear a *side pressure*, with an intention to ascertain, in some measure, the effect of the wind upon a tube. (Table II.)

6th. To ascertain the strength of small tubes of different forms of section, as cylinders, squares, or rectangles, of wrought iron, to resist best a force of compression applied in the direction of their length, as in the case of columns; the object being to determine the best form of section of small tubes to be applied longitudinally along the top of

the large tube, to enable it adequately to resist crushing, with the least quantity of metal. (Tables V., VI., and VIII.)

7th. To ascertain, as in the last article, the resistance of *plates* of wrought iron to a crushing force, applied in the direction of their length. (Tables IV. and VIII.)

8th. To obtain some knowledge of the power of tubes to sustain impact, particularly with reference to riveting. (Table III.)

9th. To determine, by bodies let fall upon tubes, the probable effect, if any, of trains rushing rapidly upon tubular bridges, to produce resilience, or springing up, at the ends. (Table III.)

10th. To determine the transverse strength of tubes stiffened in the top with cast iron, conjoined with wrought, to increase the resistance of the top to a crushing force. (Tables III. and VII.)

The nature of the experiments, and the results obtained will be better understood from the abstract of them given further on.

The principal experiments, and the deductions drawn from the whole that had been tried, were, in all cases, communicated as soon as obtained to Mr. Stephenson, with suggestions bearing on the bridge, and he adopted them or not, as he thought best.

The experiments were made upon a plot of ground, taken for the purpose, very near to Mr. Fairbairn's engineering works in Manchester. The tubes were mostly executed by him, from my directions, under Mr. Stephenson's orders, and I had men from his works to assist in making the experiments. He had, therefore, every means of knowing the objects of the experiments, and the results arrived at; and of advising Mr. Stephenson conformably to them.

The experiments being nearly ended, and the form of a tube fixed on, December, 1846, I was requested to compute its probable strength, and the deflection it would have, both from its own weight, and from any other weight laid upon it.

This proposed form of tube had two rows of cells at the top, which rendered it too heavy there, and the neutral line too high. (See Computation at the end of this Paper.)

It was, therefore, determined to have one row only at the top; these being of thicker plates than before, which had been shown by my experiments to resist crushing much better than thinner ones. The tube had other changes made in it, agreeing better with the requirements of theory and my own recommendations.

I computed, for Mr. Stephenson, the strength of this tube too (see computation on tube fixed on in March, 1847), but did not attempt to estimate the deflections, as the depth was not uniform throughout, but somewhat less near to the ends than in the middle. The error from computing the deflection, on the assumption that the tube was uniform

throughout, would, however, be very small; since in the elastic curve the flexure is principally in the middle, and nothing at the ends.

Supposing, then, the depth of the tube to be uniform, and the weight 1300 tons, the deflection would be 7·773 inches, as computed afterwards, when the weight became known *.

In the Conway tube, as first proposed to be made, 17th December, 1846, the computed deflection from its own weight, supposing that to be 900 tons, was 5·59 inches; and for a weight of 1300 tons, the deflection would be $\frac{13}{9} \times 5{\cdot}59 = 8{\cdot}07$ inches. For these matters, see pages 164 to 179 of the Parliamentary Report.

On the best Form of Section of Tubes of Wrought Iron, and the Strength of similar Tubes to resist Transverse Strain.

In the formation of a well-proportioned tube, such as it was intended *that* across the Menai Straits should be, the chief object is to make the resisting powers of the top and bottom of the tube equal and of sufficient strength, and the sides strong and stiff enough to keep, with the least quantity of metal, the top and bottom at their proper distances. The best proportions of the top and bottom can only be obtained by experiments tending to unfold the strange anomalies which wrought iron, pressed by different weights, exhibits, and which will be explained further on, when we shall have to give the results of the experiments on the resistance of plates and cells to a crushing force, applied in the direction of their length.

It may, however, be mentioned here, that tubes of different thickness bent transversely require to have the thickness of their tops and bottoms in a *different* ratio, as is shown by the experiments. This ratio should be different, too, in tubes intended to be subjected to slight strains only, and in those proposed to be broken.

The experiments on the transverse strength of tubes, in this research, are detailed in the three first Tables. They are confined to tubes rectangular in section, as it was not probable that the great one would be of any other form; and they are of simple plates, without cells in the top, the forces of resistance at the top and bottom being thus placed as far asunder as possible, and the strength thereby increased.

Table I., the first of the three, is devoted to tubes uniform throughout, and formed of plates equal in thickness in the top, bottom, and sides. The tubes of the same lateral dimensions differ in the thickness of their plates, the plates of one being twice or thrice those of another. Each of these tubes is formed to be similar in length, breadth, depth, and

* The deflection, as obtained from the bridge itself, when completed, was 7¾, or 8 in. nearly.

thickness of plates, to others varying widely from it in size, in some cases as much as eight times. And when the results from these are conjoined with those from an experiment, in Table II., on a tube 45 feet span, we obtain the comparative strength of similar tubes, varying in linear dimensions as 12 to 1. This comparison of results from tubes differing in magnitude so widely, was conceived necessary, lest, on account of the wrinkling of the plates, the defect of elasticity, and the riveting, the strength of models should not be a safe guide to that of the large tube. An abstract of Table I. has been given in page 40, and two supplements to it will be mentioned below.

Table II. contains the results of experiments on the strength of rectangular tubes, of various forms and different magnitudes, but similar in section; and as the strength of similar tubes had been shown, in the First Supplement to Table I., to vary according to the square of their lineal dimensions, or, more nearly, as the 1·9 power of those dimensions, all these tubes had their strength computed by each of these powers, on a supposition that they were of the size of the Menai tube, and 1000 tons weight. This was done to reduce them all to the same standard—that of the great bridge to be erected; and it was remarkable that the strength did not vary very greatly, whichever of the sections was taken. This arises from the sides requiring thick plates, or angle irons, to give them adequate stiffness, otherwise form of section would have great influence, as is shown by Experiments 8 and 9, Table II.; and particularly where cast iron is used in the top of the tube. The results from the large tube made in London were compared in the same manner. (For these matters, see Table VII.)

To meet, in the most moderate degree, the requirements of this research, I made, in all, 32 experiments on the transverse strength of tubes, the largest of which were 47 feet long, 45 feet between the supports, and varying in weight from 3 to 7 tons.

On the Proportions of Tubes in different Parts to resist equally a Transverse Strain.

Suppose the form and dimensions of the section of a tube, in the middle, to be fixed on, what reduction should take place in the ends, that the strength may be equally great in all parts, without waste of metal?

To determine this, a number of rectangular tubes, uniform throughout (Table I.), were broken by pressure, both in the middle and other parts; and from a general comparison of the breaking weights, both in the middle and near to the ends, in tubes of the same size, but of three different thicknesses of plates, as $\frac{1}{2}$ inch, $\frac{1}{4}$ inch, and $\frac{1}{8}$ inch, it appeared probable that uniform tubes might be reduced at the ends, in the ratio indicated by theory. For, on comparing the strengths of these tubes in

the middle and near to the ends, it appeared, from a mean of seven experiments upon tubes of the same size, and of plates $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ inch thick each, that the theoretic were to the experimental results as 142 to 146. (Second Supplement to Table I.)

The tubes subsequently made, and the results given in Table II., were therefore reduced in thickness at the ends, top, bottom, and sides, in the ratio of the rectangle of the segments at each part, and the tubes, 30 feet long, were afterwards broken, both near to the ends and in the middle. These tubes were as before of different thicknesses in the middle, and tapering towards the ends; and it was found that the thicker tubes obeyed the theoretic law, but the thinner ones became wrinkled at the sides, near to the ends. To obviate this, the sides were, in the repairs after the first experiment, stiffened in these parts by angle irons attached vertically along them, these angle irons having answered well in the large tube made in London. (For other particulars on the tubes, see Tables II., III., and VII., the last in particular.) The tubes in Table II. were ordered and undertaken in March, 1846, but none of them were executed before from July to September following.

Among the difficulties to be surmounted, in devising and constructing the tubular bridge across the Menai Straits, we have—

1st. The tendency of plates to become crippled or wrinkled on the compressed side.

To prevent this, I suggested, as mentioned before, the introduction of circular cells into the top of the wrought-iron tubes. This idea I urged strongly on Mr. Fairbairn, and mentioned it in the presence of Mr. Stephenson's assistants, during the first experiments in London, and he made a drawing of it in his note-book. After this, he had an experiment made on a tube with a corrugated top. Mr. Stephenson informs me that *he* thought of stiffening the tops of tubes by cells at the same time; a matter so obvious, that it is no wonder that two, or even three persons, should think of it at once.

2nd. Suppose, then, it were determined to stiffen the top of the tube with pipes, I propose to seek, experimentally, for an answer to the following questions: What would be the best form of section of these pipes—the square, the rectangular, or the circular? Or would it be desirable to use thick plates, or plates riveted together, so as to obtain the requisite thickness?

To determine the relative strengths of plates, and of the several kinds of pipes—say, those whose section was circular, square, or rectangular—to a crushing force, I made a great number of experiments, enough for the proposed purpose, so far as to show which form of section would best resist compression, applied in the top of the tube; though too few to develope properly, in some respects, the laws.

Some of the properties of these may be here mentioned.

1st.—*On the Resistance of Plates.*

In order to determine the resisting powers of plates, or bars of different length, breadth, and thickness, to a force of compression, applied in the direction of their length, 40 experiments were made, on plates varying in length from 10 feet to $3\frac{3}{4}$ inches, and in area of section from 6 inches to 1 inch nearly, with considerable variety in form of section.

From these experiments it appeared that the resistance of plates of the same length and breadth, but varying in thickness, was nearly as the cube of the thickness, or more nearly as the 2·878 power of it. Thus, a plate of double the thickness of another would resist flexure, or buckling, with seven or eight times the force, applied in the direction of its length; this will be seen as follows:—

The resisting powers of plates to a force of compression will vary as the breadth multiplied by some power of the thickness, when the length is the same.

Let b, $b_,$ be the respective breadths; d, $d_,$ the thickness; m, $m_,$ the weights of greatest resistance of two plates of the same length; and n the power, which may be considered as constant, when the material is not over compressed.

We have then, $$b\,d^n : b_,d_,^n :: m : m_,$$

Whence, $$\frac{b\ d^n}{b_,d_,^n} = \frac{m}{m_,}$$

Or, $$\left(\frac{d}{d_,}\right)^n = \frac{m}{m_,} \times \frac{b_,}{b}$$

$$\therefore n = \frac{\text{Log.}\dfrac{m\ b_,}{m_,b}}{\text{Log.}\dfrac{d}{d_,}}.$$

Comparing the results in Table IV., we have as below:—

Length of Plates.		Dimensions of section.	Weight of greatest resistance.	Weight per square inch of section in greatest resistance.	Value of n.
Ft.	In.	In. In.	lbs.	Tons.	
10	0	3·00 × 1·51	46050	4·538	2·622
		3·01 × ·766	7793	1·508	
10	0	3·00 × 1·51	46050	4·538	3·073
		2·99 × ·995	12735	1·911	
7	6	3·00 × 1·53	91746	8·923	2·898
		2·983 × ·5023	3614	1·076	
7	6	3·005 × ·9955	29619	4·425	3·064
		2·983 × ·5023	3614	1·076	
5	0	3·01 × ·995	54114	8·066	2·735
		2·98 × ·507	8469	2·502	
				Mean . . .	2·878

Hence, the difficulty presented by the buckling of the plates in the top of the tubes might be overcome, by properly adjusting their thickness.

This conclusion, it will be seen, was arrived at through the comparison of plates bearing not more than from 1·076 ton to 8·923 tons per square inch of section. If the load per square inch had been much greater, the results would have been anomalous and very different, as in the case of rectangular tubes compressed in the direction of their length, further on.

Resistance of Square Columns of Wrought Iron.

It appeared, likewise, from the experiments on plates, that the strength of square pillars of wrought iron, long enough to become bent without the material being much crushed, is nearly as the 3·59 power of the lateral dimensions, or as $d^{3·59}$, where d is the side of the square, the length being constant. The law of the resistance of wrought iron is, therefore, not widely different from that arrived at in my experiments on cast-iron pillars (Phil. Trans., 1840), the mean from pillars of this material being 3·6 nearly.

To prove this, or, in other words, to obtain the strength of a square column, as dependent on its lateral dimensions, the strength of the plates in Table IV. was reduced in the ratio of the breadth to the thickness for the strength of the column, if square; and the comparative results were afterwards obtained, as follow:—

Length of Bars compared.		Lateral dimensions (or side of square) of bar.	Strength or Weight of ultimate resistance.	Power (n) of the lateral dimensions, on which the strength depends.
Ft.	In.	Inches.	lbs.	
10	0	·766 1·51	1948 23025	3·56
10	0	1·00 1·5	4245 23025	4·17
7	6	1·02 1·53	10236 45873	3·69
7	6	·5 1·00	583 9873	4·08
5	0	·5 1·00	1411 18038	3·67
2	6	·502 1·00	4216 27212	2·69
2	6	·502 ·76	4216 15946	3·28
			Mean . . .	3·591

Resistance of Pipes, or Hollow Cylinders.

To ascertain the resistance of cylindrical tubes to a force of compression, 37 experiments were made, as these were, comparatively, of an inexpensive character, and would throw a good deal of light upon the theory, and upon the resistance of other forms of tube which could not be investigated far without great expense.

From the results just obtained with respect to the resisting powers of square pillars of wrought iron, of a constant length, that dimension being great compared with the side, we may infer that round ones would follow the same law; the strength, as before, varying as $D^{2.59}$, D being the diameter.

This inference is agreeable to what I found to obtain in cast-iron pillars in the experimental paper, on the strength of pillars previously alluded to.

With respect to the strength of hollow cylindrical columns, Poisson has shown (Mécanique, tome 1, page 620) that, according to the theory of Euler, the strength would vary as $\frac{D^4-d^4}{l^2}$; and from my own exments on cast-iron pillars (Phil. Trans., 1840, page 414, and elsewhere), it varied as $\frac{D^{3.55}-d^{3.55}}{l^{1.7}}$ nearly, where D was the external diameter, d the internal, and l the length. Hence we may infer that the strength of a wrought-iron pillar, whose length was such that it would yield by bending before it had sustained a pressure to injure much the material, would be as

$$\frac{D^{2.59}-d^{2.59}}{l^n},$$

where $n = 2$, in very long pillars; but in shorter ones the value of n will be reduced to any degree, or so that $n = o$, or that $l^n =$ a constant, in very short columns; showing the weakness of wrought iron to sustain compression and its unsuitableness for pillars.

The law indicated by $\frac{D^{2.59}-d^{2.59}}{l^2}$

could only apply where the straining force in the direction of the tube was not more than 8 tons or 9 tons per square inch, as in the case of plates mentioned before.

If the force of compression be greater than this, the law indicated above would not apply, as a considerable change takes place in the nature of the material, and beyond about 12 or 13 tons per square inch of section the metal, in most cases, cannot be usefully employed, as it will sink to any degree, though in hollow cylinders it will sometimes bear 15 or 16 tons per square inch. These preliminary remarks will receive illustration and much further extension from the experiments in Tables VI. and VIII.

Resistance of Tubes, Rectangular in Section, to a force of Compression in the Direction of their Length.

To determine the strength of tubes whose section was a square or rectangle. For this purpose 14 tubes, each 10 feet long, and of different form, size, and thickness of plates, were made (see Table V.), and their resisting powers obtained; the whole number of experiments on these tubes being 29. From these it appeared that square rectangular tubes, 4 to 8 inches in the side of the section and 10 feet long, bore as follows:—

Rectangular 8 × 4.		8-inch tubes.		4-inch tubes.	
Thickness of plates.	Strength per square inch of section.	Thickness of plates.	Strength per square inch of section.	Thickness of plates.	Strength per square inch of section.
Inch.	Tons.	Inch.	Tons.	Inch.	Tons.
.....	.....	.....	.....	·03	4·9
·061	6·79	·06	5·9	·06	8·6
.....	.....	.....	.....	·083	11·24
.....	.....	·139	9·1	·134	9·64
.....	.....	.....	.....	·134	10·36 in 7 ft. 6 in. tube.
.....	.....	·219	11·48	.....	.....
·264	12·015	.....	.....	.....	.....

These results are very singular; they show that, in the *crushing* of rectangular tubes, the strength, instead of being nearly as the third power of the thickness, as was found to be the case in incipient strains (page 46), is so much reduced that, to produce double the strength, four times the thickness of the metal is required.

	Inch.	Inch.		Tons.	Tons.	Tons.
Thus, plates of	·03	and ·134	in thickness, give strengths of	4·9	and 9·64	or 10·36.
And „	·061	and ·264	„ „	6·79	and 12·015.	

It also appears that, when the thickness of the plates of the tubes is the same, the strength of the smaller ones is greater than that of the larger, as may be seen from the strengths of tubes of equal thickness placed opposite to each other. It likewise appears from Table V. that, in square cells, compressed to a high degree, the length has little influence; for tubes 10 feet, 5 feet, and 2 feet 6 inches long, all bear nearly the same pressure.

Further Remarks on the Experiments to ascertain the Power exerted by Plates and Tubes to sustain Longitudinal Compression.

When the pressure applied is not greater than about 9 tons per square inch, the material appears to resist according to the laws stated in the

remarks previously made, a plate of the same length and breadth as another of twice the thickness having seven or eight times the strength; but when the pressure is greater than that, the metal, becoming crushed, causes a deviation from those laws, and the more so as the pressure increases; and that to such a degree that, in rectangular tubes highly compressed, a plate of twice or three times the thickness will be required to be employed in order to obtain double the resisting power.

By comparing the resistance of rectangular tubes of different sizes and the same thickness of metal, we find that the tubes of smaller lateral dimensions resist compression better than the larger ones; and the four-inch squares better than the rectangles 4 × 8; and that none but the thickest plates used would resist with twelve tons per square inch. The hollow cylinders gave better results, and we find some of them requiring 15 and 16 tons per square inch to crush them longitudinally. The particulars of these various experiments are in Tables IV., V., VI., and VIII., which last is an abstract of the others.

As the laws governing the resisting powers of tubes and plates, subjected to compressions approaching those necessary to crush the material, could not be inferred with certainty from the experiments, a datum of considerable practical importance was in all cases obtained—the *ultimate resistance per square inch of section* in the body, and often *that* with which wrinkling, corrugation, or flexure appeared to commence.

Comparative Strength of Wrought and Cast Iron to bear Pressure in the Direction of the Length.

From numerous experiments to determine the pressure which wrought iron would bear as a column, I found that, beyond about 12 tons per square inch, it was of little or no use in practice; and, as my former experiments had shown that cast iron would bear much greater pressure than wrought, it became desirable to compare the relative compressions of those two metals with equal forces, as it seemed highly probable that cast iron combined with wrought would be a valuable substitute for wrought iron alone in the top of the tube; a change which, if practicable, would be very desirable, considering the anomalies to which wrought iron, when too much compressed, is liable.

For this purpose bars of wrought iron and of cast iron were formed, 10 feet long and 1 inch square; and these, by an apparatus invented for that purpose, were preserved in a vertical position, quite straight, whilst they were compressed by successive weights. The decrements of the lengths of the bars from the weights were then obtained in thousandths of an inch, and the sets, or decrements after the weights were removed, were likewise obtained.

From these experiments it appeared that cast iron was decreased in

length about double what wrought iron was by the same weight; but the wrought-iron bars sunk to any degree with little more than 12 tons per square inch, whilst cast iron required twice, or perhaps three times, the weight to produce the same effect.

Weights producing nearly equal decrements of lengths, in bars of cast and wrought iron 10 feet long and 1 inch square, nearly, are as follow, the decrements being put opposite to each other:—

Cast-iron bar. Area of section, 1·031 × 1·029.		Wrought-iron bar. Area of section, 1·025 × 1·025.		Cast-iron bar. Area of section, 1·028 × 1·047.		Wrought-iron bar. Area of section, 1·016 × 1·02.	
Weight laid on the bar.	Decrease of length by that weight.	Decrease of length of the bar.	Weight producing that decrease.	Weight laid on the bar.	Decrease of length by that weight.	Decrease of length of the bar.	Weight producing that decrease.
lbs.	Inch.	Inch.	lbs.	lbs.	Inch.	Inch.	lbs.
...	...	·028	5098	...	...	·027	5098
5054	·054	·052	9578	5098	·043	·047	9578
7316	·078	·073	14058	...	...	·067	14058
...	...	·085	16298	9578	·082	·089	18538
...	...	·096	18538	11818	·102	·100	20778
9578	·102	·107	20778	...	...	·113	23018
...	...	·119	23018	...	...	...	...
11818	·126	·130	25258	14058	·123	·128	25258
...	...	·142	27498	...	...	·143	27498
14058	·151	·154	29738	...	...	...	...
...	...	...	...	18538	·166	·163	29738
20778	·173	·174	31978	...	...	...	...
...	...	...	...	20778	·189	·190 to ·261	31978 " in ½ hour.
21898	·210	·214	34218	23018	·212		
23018	·247	...	...	27498	·254	·269 to ·282	31978 " in ¼ hour.
27498	·300	...	...	31978	·302		
31978	·357	...	...	36458	·355	·328	" repeated.
36458	·423	...	...	40938	·414		
40938	·503	...	...	45418	·481	From ·190 to ·328 in 1¼ hour.	
45418	·565	...	...	49898	·558		
49898	·694	...	...	54378	·667		
...	·749			Discontinued the experiment after this weight.			
54378	·865						
63338	Uncertain.						

To this question of the introduction of cast iron Mr. Stephenson gave great attention, as indeed he did to every other, with respect to its bearing upon the bridge. The danger of wrought and cast iron not acting well together in the top of the tube,—especially as, under the smaller compressions, the wrought iron would be doing double the duty of the cast iron, and there was an uncertainty as to the effect of their different expansions,—these, doubtless, together with the late season at which the change was proposed to Mr. Stephenson, prevented his adopting the cast iron as an auxiliary. He considered it safer to render the thickness of the cells as great, and their size as little as practicable, in order, as much as possible, to prevent buckling.

The set, or permanent decrement of length, after the weight was removed, was found, from many experiments, to be nearly as the square of the compression; and it was well expressed by the following formula:—

$$\delta = \cdot 5\, d^2 + \cdot 0028.$$

The results of these experiments having needed a little correction, on account of an inaccuracy in the scale, the formula becomes

$$\delta = \cdot 543\, d^2 + \cdot 0013, \text{ where } d \text{ is in parts of an inch.}$$

The bars were of Low Moor iron, 10 feet long, and cast to be one inch square.

In the experiments on tubes strengthened by cast iron to resist a transverse strain, no practical difficulty was found as to riveting the two metals together; the cast iron never breaking by the blows, and the wrought iron and it accommodating themselves to each other. Where the cast iron was opposed to double the quantity of wrought iron, the wrought iron failed first, and the increase of strength was great. (See Tables III. and VII.)

Transverse Strength of Tubes laid on their Sides, compared with their Strength when Erect.

In tubes, of which the breadth was two-thirds of the depth, the strength on the side, from a mean of two experiments, was found to be $\frac{15{\cdot}25}{26{\cdot}1}$ of the vertical strength.

These experiments were made to obtain some idea of the power of a tube to resist the action of the wind upon its side.

Effect of Impact upon Tubes.

To ascertain the effect of impact and vibration upon the riveting of tubes, I subjected the large tube, 47 feet long, and about 6½ tons

weight—after it had been done with for other purposes—to a series of small impacts from a heavy body suspended as a pendulum, and striking it horizontally. The tube was sustained in a horizontal position by vertical supports, 45 feet asunder; and it was struck in the middle by a mass of iron weighing 2 tons 15 cwt., suspended by a radius of 22 feet. At the place of impact the tube was protected from much injury by a cast-iron frame placed inside of it, and on the outside by a piece of wood 2½ inches thick, to receive the blows. The results of this experiment showed that long-continued impact, producing a deflection of less than one-fifth of what would be required to injure the tube by pressure, was completely destructive to the riveting. The great weight of the Menai and Conway bridges, by destroying all sensible vibration, will obviate the danger here pointed out.

The same thing may be said of the resilience, or springing up, of the ends of the tube, which, like the former, was made the subject of an experiment. The details of both of these experiments are given at the end of Table III.

Many matters, little noticed in this introductory sketch, will be found in the remarks accompanying the tabulated results of the experiments on the transverse strength of tubes, of which an abstract, together with a general comparison of results, is given in Table VII.

The following abstract of a communication which I made to the British Association, at its meeting at Southampton, in 1846, will throw some light on the matter as it stood at that time. It is extracted from the "Railway Chronicle," October 3, 1846:—

Having last year, about August, been requested to take a part in the experiments then in progress with respect to the proposed tubular bridge over the Menai, on the subject of which I had been previously consulted, I went to London for the purpose; and finding that a number of experiments had been made upon cylindrical and elliptical tubes, and a few upon rectangular ones, I expressed a conviction that the tubes then tried, and others proposed, would not be the best for the intended purpose, though they would afford valuable introductory knowledge. I urged that the tube, to bear the greatest weight, must be formed as a large beam or girder, having its top and bottom equally capable of resistance, and with sides strong and stiff enough to keep them at their proper distance; and as it was found that the tube usually gave way at the top, by buckling, and hence would require additional metal, and might perhaps be very heavy, I suggested that the top should be formed of cylindrical tubes, as I felt that these tubes, or something analogous to them, would best resist the strain to which the top would be exposed. I was led to these conclusions from the results of my previous experimental inquiries on the strength of beams and pillars. Mr. Fairbairn

made a sketch of such a tube in his experiment book, and in a subsequent experiment he had a tube made with a corrugated top, employing the principle in another form; and the results from this tube were very satisfactory. At the conclusion of these experiments, which were conducted by my friend Mr. Fairbairn, I felt deeply the want of additional information, particularly such as would bring the matter within reach of the mathematician; as, without that, the utmost danger would accrue in so large and novel an application of the material, and in which a tendency of the compressed part to give way by wrinkling, threw a doubt as to the bearing powers.

To meet some of the difficulties, I made several experiments, the results of which are given in my report alluded to by Mr. Fairbairn, and in a letter to Mr. Stephenson pointing out others. To this letter Mr. Stephenson was pleased to return an answer, March 14, requesting me to make another course of experiments, and investigate the subject fully, and to my own satisfaction, particularly with regard to its scientific bearings; at the same time requesting Mr. Fairbairn to prepare everything for the purpose according to my wishes. To carry Mr. Stephenson's wish into effect, a large and expensive apparatus was necessary; and this was constructed, and a plot of land was engaged to erect the apparatus, and conduct the experiments upon. One part of this apparatus was to break large tubes transversely, and the other was to ascertain the resistance of bodies to a crushing force, in order to determine the best form of the tube proposed to be constructed for the bridge.

Six tubes were ordered; three of them each 47 feet long, 3 feet deep, and 2 feet wide, the thickness of the metal tapering from the middle towards the end, in the ratio indicated by theory, for the strength to be equal in every part. The other three tubes were of two-thirds the lineal dimensions of the former in every respect. I had ascertained, from several experiments upon tubes broken by weights laid successively on the middle and near to the ends, that the above reduction in strength towards the ends might safely be made.

Besides the above, Mr. Fairbairn undertook to obtain tubes of various forms for crushing, as mentioned above; but the great length of time taken in preparing these things, some of which are not ready at present, has lessened considerably the importance of my efforts, though I am persuaded they have had a very beneficial influence on the inquiry. I will give some of the leading results, and, first, those from the fracture of two *similar* tubes, as in the following table:—

Length of tube.	Weight of tube.	Distance between supports.	Depth of tube.	Breadth of tube.	Thickness of metal, in 16ths of an inch.			Breaking weight, in tons.
Ft. In.	Cwt. qrs.	Ft.	Ft.	Ft. In.	Top.	Bot.	Side.	
31 6	20 3	30	2	1 4	6	4	2	26·1
47 0	61 0	45	3	2 0	9	6	3	65·5

The ultimate deflection of the former tube was about $2\frac{3}{4}$ inches, and that of the latter about $3\frac{1}{2}$ inches.

To ascertain the power of such a tube to bear a side strain, as from the action of the wind, the smaller tube above, after being well repaired, was laid on its side and broken, from a mean of two experiments, with 15·2 tons. Hence, its *lateral* strength was $\frac{15}{26}$ of its *vertical* nearly; and in a narrower tube it would be considerably less.

A number of experiments were made to determine the resistance of plates of wrought iron to a force of compression, and from these considerable information has been obtained with respect to the laws of their resistance to flexure or buckling.

The following table contains the weights, external dimensions, and weights of greatest resistance, of some of the tubes, 10 feet long, which were subjected to a force of compression :—

CYLINDRICAL TUBE.		
Weight of tube.	External diameter of tube.	Weight of greatest resistance.
lbs. oz.	Inches.	lbs.
47 10	2·84	31,828
45 15	2·99	37,356
59 0	4·05	47,212
64 4	4·06	49,900
RECTANGULAR TUBE.		
43 $14\frac{1}{2}$	4·1 × 4·1	19,646
65 8	8·15 × 4·1	23,289
82 0	8·1 × 4·1	43,673
91 1	8·0 × 8·0	27,545

The rectangular tubes above are all of plates $\frac{1}{16}$th of an inch thick. They were all simple rectangles or squares, except the last but one, which had a division in it, making it into two squares.

The proposed tubular bridge has undergone alterations in consequence

of my experiments and recommendations*. 1st. In the thickness of the side, to enable it better to resist the action of the wind. 2nd. In the top being made straight instead of curved, to allow the escape of the steam. 3rd. In reducing the rectangular cells at the top.

In this last instance, however, since rectangular tubes are weaker than square ones to resist compression, and these much weaker than cylindrical ones, I hope the latter will be substituted for the former, as it would, according to the preceding experiments, effect a saving of one-fourth of the metal in the top, leaving the strength the same.' This matter is of the more consequence as the weight of the tubular bridge will bear so large a proportion to the breaking weight.

* The form of the bridge underwent great changes, in the top particularly, long after this time, as will be seen from the Paper, pages 164 to the end.

DESCRIPTION OF ILLUSTRATIONS.

Nos. I. and II. Bridge under Railway, on the South-Eastern Branch Line to Ashford, Rye, and Hastings.

This is reduced from the drawings furnished by P. W. Barlow, Esq., to the Commissioners to inquire into the application of Iron. It is engraved in their Report under the No. 7, of Appendix 1.

The objection to this kind of bridge lies in the fact that its powers of resistance depend entirely upon the bolts at the flanges. Such constructions require to be very carefully watched; for in so damp a climate as ours, wrought iron is necessarily exposed to the deleterious effects of rust. Moreover, if the theory be correct, that the crystalline nature of wrought iron is likely to be affected by repeated percussion, there must be especial danger in bridges of this description.

The design of this bridge is certainly very elegant; the form of a straight beam is made to convey as much of what we may call architectural expression as possible.

No. III. Cheltenham and Great Western Union Railway. Saint Mary's Viaduct.

This drawing is also reduced from the Report to which it had been contributed by the author, I. K. Brunel, Esq.

Mr. Brunel stated that he objected to the use of cast-iron girder bridges when they attained a considerable span; and that in his own practice he preferred compound structures into which wrought iron and wood entered, as the principal materials. He illustrated this practice by the drawing before us, which really presents a very beautiful adaptation of the ordinary principles of framing to road purposes. In positions where cast iron is dear, or the means of transport deficient for the conveyance of large heavy beams, nothing can be superior to the design of this viaduct. It is a very valuable study for an engineer, practising in a new country especially; although the scantlings of the timber are not such as are usually found in such circumstances.

The drawing is sufficiently detailed to dispense with further description.

No. IV. The Chalk Farm Bridge.

Certainly this is not either a very elegant, or a very logical specimen of the box girder construction. It is added principally to illustrate the modifications which the use of plate iron is susceptible of. The only advantage (and after all it is a great one), gained by the substitution of this particular description of wrought-iron bridge, for a common cast-iron girder one, is to be found in the facility it affords of keeping down the level of the roadway. The cast-iron top is also less liable to rust than a wrought-iron tube would have been.

No. V. Mr. Fairbairn's Bridge to carry Railroad over the Turnpike Road near Blackburn.

Mr. Fairbairn refers with very justifiable satisfaction to this bridge in his evidence before the Commission. As an essay towards the introduction of a new system of bridge building, it certainly was a very remarkable work; and Mr. Vignolle's readiness to employ it is highly creditable to his sagacity.

As will be seen in the drawing, the strength of the middle beam is increased, to offer greater resistance in the case of the passage of trains on both lines. Mr. Fairbairn recommends that in ordinary cases only two external girders, however, be used, and that the strength of the transverse timbers or platform be augmented. This must be a matter of economical consideration after all, for it might arise that the extra expense of the floor of the bridge, with only two girders, would be greater than that occasioned by the introduction of a third. The simplicity of structure Mr. Fairbairn considers as the main recommendation of the bridge with two girders, is not a matter of much importance, if any serious objection on the score of expense interfere with its attainment.

We have not joined any details of this bridge, because subsequent experience has led to modifications in the execution of these works. Enough is shown to enable the general arrangement to be understood, and to show the effect of the bridge.

Mr. Fairbairn mentions that it has been exposed to the weight of a locomotive passing at the rate of ten miles an hour, and falling through a height of $1\frac{1}{8}$ inch and that the girders resumed their original form immediately the load was removed.

No. VI. Ballysimon Bridge, Waterford and Limerick Railway. Rich. B. Osborne, C.E.

This bridge is an application of cast and wrought iron in framing, upon the principle first introduced by the American engineers, upon the Boston and Albany Railway. Mr. Osborne recommends the adoption of this principle very warmly, on the score of its economy. He states that the Ballysimon Bridge, exclusive of cross beams and roadway, only cost £1289. The span, in clear, is 86 feet, and the bridge crosses the railway at an angle of 45°.

The Commissioners appear to have arrived at very unfavourable opinions relative to the merit of all modifications of lattice bridges; but they give no experiments to confirm their decision, nor was any practical evidence given to justify it. The most valid objection to them which appears to have been yet discovered, is their liability to lateral displacement from the warping of the timbers, and the effect of the wind upon the wooden bridges of this construction when the span is considerable. The substitution of cast and wrought iron in the manner Mr. Osborne recommends removes the first objection; and also the second to a great extent. It is to be hoped that the economical principle of these bridges will not be abandoned, without at least some more satisfactory examination.

The appearance of this bridge would have been improved if the top rail had been made to look larger; and also if the ornamental brackets at the sides had been brought down to the bottom line of the girders, instead of only reaching the roadway.

The area of the top chord is		$18\frac{3}{4}$	inches.
,,	coping plate	$26\frac{3}{8}$	,,
,,	bottom chord	$33\frac{3}{4}$	,,
,,	bolster plate	11	,,
,,	brace in centre	$12\frac{1}{2}$	,,
,,	,, at foot	16	,,

This bridge sunk $\frac{5}{16}$ths of an inch when tested with a weight of 80 tons by the Inspector of Railways.

No. VII. Hollow Girder Bridge over Ardwick Branch Railway.

The drawings connected with this bridge were appended to the written evidence given by J. Hawkshaw, Esq., before the Commissioners.

The span of the bridge was, in the clear, 100 feet; the length of the girders, over all, 108 feet; leaving thus bearings 4 feet long on each side.

The bottom is formed of a double layer of $\frac{5}{16}$ths of an inch plates, with cover-joints 2 feet 8 inches long each. The sides are of half-inch plates over the bearings only, and of $\frac{5}{16}$ths of an inch plates throughout the rest of the bridge; the plates butt against one another, and the joints are covered by a strip $4\frac{1}{2}$ inches wide, stiffened internally by angle-iron. The tubes at top, and the bottom plates, are attached to the sides by means of angle-iron, 3 inches by 3, on the sides.

The tubes at the top of the girders are made with bottom-plates $\frac{6}{16}$ths of an inch thick in the centre; but the vertical plates diminish in thickness as they approach the bearings. The elevation shows in what manner. The angle-iron is 3 inches by 3 on the sides. The top plates of the tubes are $\frac{8}{16}$ths of an inch thick.

The rivets of the upper tubes, and of the bottom-plates, are 4 inches from centre to centre. Those of the side-plates, and the angle-irons connecting the top and bottom therewith, are 3 inches from centre to centre.

The bridge, as will be seen from the section, consists of a roadway and a double line of rails. The platform is composed of a series of box-girders, 12 inches deep over all, by 5 inches wide, measuring over the side-plates, which are $\frac{9}{16}$ths of an inch thick. The top plates are $\frac{6}{16}$ths of an inch thick; the bottom plates $\frac{5}{16}$ths; and both are 10 inches wide. Angle irons, $2\frac{1}{4}$ inches on the sides, attach them to the vertical plates, with rivets 3 inches apart from centre to centre. These beams are placed 6 feet apart, and are covered with a layer of 4-inch planking, the baulks under the rails being 10 inches square.

No. VIII. Bridge over Lagunes of Venice.

This remarkable construction, by means of which "la vedova dell' Adriatico" is connected with the main land, was commenced in the year 1841, under the orders of an Italian engineer named Milani. It begins immediately under the guns of the Fort Malghera, and terminates in Venice at the Sacca di Santa Lucia. The total length is 3938 yards; the width in the ordinary portions 29 feet 7 inches. In the centre is a large open space, upon which a battery of canon could be mounted, 278 feet 10 inches long by 133 feet 4 inches wide, flanked on each side by smaller open spaces 90 feet 3 inches long by 55 feet 9 inches wide. The two portions thus formed are subdivided by six secondary spaces or platforms, 342 feet long by 55 feet 9 inches wide. These are again subdivided into bays, 7 in number, containing 5 arches each, At the end of each bay a wider pier, 47 feet 4 inches long by 33 feet 4 inches wide, is introduced to act as an intermediate abutment. There are thus in all 210 arches.

As shown on the drawing, the chord of the arches is 33 feet 4 inches; the versed sine is 6 feet; the thickness at the key is 2 feet 2 inches; at the springing it is 3 feet 2 inches.

The piers and the imposts are executed in ashlar, of a calcareous stone derived from Istria. The spandrils are of brick; the string course and the parapets of the Istrian stone. The arches are coated with a mixture of lime and puozzolano. A provision is made to receive the pipes through which it is proposed hereafter to convey to Venice the water of the river Sile, for the supply of the domestic wants of the inhabitants.

This bridge was opened to the public early in the year 1846. The total cost was about £180,000 sterling.

The piers were founded upon piles, and by means of cofferdams. The length of the piles varied; but on the average they were about 21 feet.

No. IX. Viaduct of Beaugency, on the Orleans and Tours Railway, France.

This railway does not contain many important works; but it is remarkable for the perfection with which all its details have been carried out. The viaduct represented in this engraving is the largest work it comprehends, and it is certainly one of those entitled to praise on the score of the execution.

The length from face to face of abutments is 829 feet, divided into 5 bays, by means of 4 intermediate piers; each bay contains 5 arches. There are thus 25 arches in all, of 27 feet 7 inches span, semicircular. The greatest height of the rails above the concrete was 61 feet 8 inches.

The dimensions of this viaduct are not very logical: for instance, the arch is deeper at the crown than it need have been; the piers do not increase sufficiently in the middle of their height; whilst the lower courses are larger than they need have been. But this, and also the Venetian viaduct, may be cited as examples of the very rational mode of constructing such works in bays, with stouter intermediate piers, to guard against the possibility of the fall of any one arch compromising the solidity of the whole structure.

The proportion between the surface of the ordinary piers, at the springing, to the distance from centre to centre of the piers, is as 1·23 to 1.

The arches are executed in ashlar; the outside of the bases and the quoins are of that material, as are also the imposts, the string, and the parapet. The other portions of the work are executed in coursed rubble, or, to use the French term, "*moëllon smillé*."

No. X. Bridge over the Canal St. Denis.

This bridge, upon the Northern Railway, from Paris to the Belgian frontier, is erected at a very short distance from the fortifications of the town.

It is erected upon the principle introduced by M. Polonceau in the Bridge of the Carrousel, to obviate the practical difficulty of obtaining sound castings of great length. It is ingenious, and the mode of filling in the spandrils is certainly elegant; but it is questionable whether the breaking of the joints in the arch beams does not prevent their acting freely as voussoirs, especially as the longitudinal joints are so keyed that the two portions of the arch are rendered, as it were, one beam.

The abutments are executed in ashlar, backed in with coursed rubble masonry. The radiating courses behind the arches are entirely of ashlar.

COMPUTATIONS to determine the Situation of the Neutral Line, together with the Strength and the Deflexion of the Tubular Bridge proposed to be erected for the Chester and Holyhead Railway across the River at Conway. The data are taken from drawings supplied December 17, 1846.

PROBLEM 1.

To find the position of the neutral line in the proposed bridge across the river at Conway,

We shall assume the material of which the bridge is made to be perfectly elastic, and, when that is the case, the neutral line may be shown to be in the centre of gravity of the section, the areas of the sections of tension and compression being inversely as the distances of the centres of gravity of those sections from the natural line; or, in other words, area of section of tension $\times e =$ area of section of compression $\times c$, where e is the distance of the centre of gravity of the extended part, and c that of the compressed part.

In the proposed tube, the cellular top is composed of three horizontal plates, and ten vertical ones, including those on the sides opposite the cells; and we shall assume the thickness, a, of all the plates to be the same, viz., half an inch.

The whole width is 14 feet 1 inch; whence 14 feet 1 inch multiplied by 3 gives 42 feet 3 inches = length of horizontal plates.

The depth of the vertical plates is 3 feet; therefore $3 \times 10 = 30$ feet = length of vertical plates.

The whole length of the plates is, therefore, $42\frac{1}{4} + 30 = 72\frac{1}{4}$ feet = 867 inches; therefore, $867 \times \frac{1}{2} = 433\frac{1}{2}$ square inches, the whole area of the section of the plates composing the cells at the top of the tube. The corners of these cells contain, in addition, 80 angle irons, the section of each of which is $6{\cdot}5 \times {\cdot}43 = 2{\cdot}794$ inches, or $2{\cdot}5$ square inches nearly, deducting for rivet holes; whence, $80 \times 2{\cdot}5 = 200$ square inches, the area of their sections.

We have, therefore, $433\frac{1}{2} + 200$, or $633\frac{1}{2}$ square inches nearly = the whole area of section of the cells, which we will call A. The centre of gravity of this mass is in the middle.

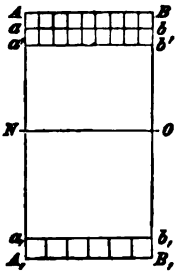
The cellular bottom of the tube, as proposed, is composed of three horizontal plates, and seven vertical ones, including those on the sides opposite to the cellular part; all these plates are to be half an inch thick.

The length of the horizontal plate is (14 feet 1 inch) $\times 3 =$ 42 feet 3 inches = 507 inches.

The length of the vertical ones in these cells is (1 foot 9 inches) $\times$ 7 = 147 inches; whence the length of all the plates in these cells is 507 + 147 = 654 inches, and the area of their section 654 $\times \frac{1}{2}$ = 327 square inches. In these cells there are likewise 32 angle irons, the area of the section of which is 33 $\times 2\frac{1}{2}$ = 80 square inches. We have, therefore, 327 + 80 = 407 square inches, which we will call $A_{,,}$ in the section of the plates and angle irons; and the centre of gravity of these cells (1 foot 9 inches wide) is a foot from their top, nearly, or more accurately 11·026 inches.

Note.—We have added the area of section of the angle irons to that of the plates, though it is probable that those in the lower part of the tube will not act with nearly their whole tensile force, through want of being adequately united at the ends.

Suppose the accompanying diagram to represent a section of the tube, in the middle, and let (N O) be the neutral line. Then if we put—



A = the area of section of the cellular top of the tube = 633 square inches, nearly;

$A_{,}$ = the area of section of the cellular bottom of the tube = 407 square inches, nearly;

$d = (a'\,a_{,}) = 21$ feet $6\frac{7}{8}$ inches = 258·875 inches;

$c = \frac{1}{2}(A\,a') = 18{\cdot}75$ inches, the distance of the centre of gravity of the upper cells from the lower side of ($a'\,b'$);

$g = 11{\cdot}026$ inches, the distance of the centre of gravity of the lower cells from the top of ($a_{,}\,b_{,}$);

t = thickness of side ($a'\,a_{,}$), or ($b'\,b_{,}$) = $\frac{1}{2}$ inch;

$x = (a'\,N)$ the distance of the neutral line from the bottom of the top cells;

A' = the additional area of ($A\,B$) above the area of ($a\,b$), or ($a'\,b'$) = 10·56 inches, if the plates in ($A\,B$) be made $\frac{9}{16}$ inch thick, or $\frac{1}{16}$ inch thicker than the others;

e = distance of the centre of gravity of A' from the bottom of ($a'\,b'$) = $2c + \frac{1}{3\,2}$ = 37·53 inches;

$\therefore\ x+e$ = distance of the centre of gravity of A' from the neutral line;

$x+c$ = " " " A "

$d-x+g$ = " " " $A_{,}$ "

$\frac{x}{2}$ = " " $2tx$ "

$\frac{d-x}{2}$ = " " $2(d-x)\,t$ "

The two last being the distances of the centres of gravity of the sides ($a'\,a_{,}$), or ($b'\,b_{,}$), above and below the neutral line. Therefore,

$(x+e)A'$ = moment of A', with respect to the neutral line . (1).

$(x+c)A$ = „ A, „ „ (2).

$(d-x+g)A_,$ = „ $A_,$ „ „ (3).

tx^2 = „ $2tx$, „ „ (4).

$t(d-x)^2$ = „ $2(d-x)t$, „ „ (5).

Equating the moments in (1), (2), and (4), with the moments in (3) and (5); that is, equating the moments on one side of the neutral line with those on the other, we shall have,

$$(x+e)A'+(x+c)A+tx^2=(d-x+g)A_,+t(d-x)^2,$$

$$A'x+A'e+Ax+cA+tx^2=dA_,-A_,x+A_,g+td^2+tx^2-2tdx,$$

$$(A'+A+A_,+2td)x=(d+g)A_,+td^2-Ac-A'e.$$

$$\therefore x=\frac{(d+g)A_,+td^2-Ac-A'e}{A+A'+A_,+2td} \quad . \quad . \quad . \quad . \quad . \quad (6).$$

Cor.—When $A'=o$, the equation (6) will become,

$$x=\frac{(d+g)A_,+td^2-Ac}{A+A_,+2td} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7).$$

From formula (6) we have,

$$x=\frac{407(258\cdot875+11\cdot026)+\frac{(258\cdot875)^2}{2}-633\times18\cdot75-37\cdot53\times10\cdot56}{633+10\cdot56+407+258\cdot875}=$$

$$\frac{109849\cdot707+33508\cdot13-11868\cdot75-396\cdot32}{1298\cdot875+10\cdot56}=\frac{131092\cdot767}{1309\cdot435}=100\cdot12 \text{ ins.}$$

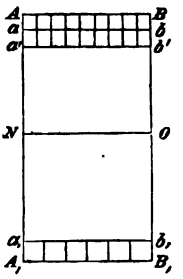
From formula (7) we have,

$$x=\frac{407\,(258\cdot875+11\cdot026)+\frac{(258\cdot875)^2}{2}-633\times18\cdot75}{633+407+258\cdot875}=$$

$$\frac{109849\cdot707+33508\cdot13-11868\cdot75}{1298\cdot875}=\frac{131489\cdot087}{1298\cdot875}=101\cdot23 \text{ inches.}$$

Problem 2.

To find the moments of the forces of the plates, and the strength of a perfectly elastic tubular beam, whose section in the middle is represented by the figure annexed, the beam being supported at the ends, and loaded by a weight in the middle.



F 2

The situation of the neutral line (NO) having been determined by the previous inquiry—

Let $a = (AN)$ the distance of the neutral line from the top;
$a_{,} = (A_{,}N)$ „ „ „ bottom;
$b = (AB) = (A_{,}B_{,})$ the whole breadth;
$c = (Aa) = (aa')$;
$c_{,} = (A_{,}a_{,})$;
t = thickness of plate (AB), increased so that its sectional area may include that of the angle irons;
t' = thickness of plate (ab), „ „ „
t'' = „ $(a'b')$, „ „ „
$t_{,}$ = „ $(A_{,}B_{,})$, „ „ „
$t_{,,}$ = „ $(a_{,}b_{,})$, „ „ „
s = „ $(AA_{,})$ or $(BB_{,})$ „ „
s' = thickness of all the vertical plates between (AB) and $(a'b')$, exclusive of the sides;
$s_{,}$ = „ „ $(A_{,}B_{,})$ and $(a_{,}b_{,})$ „
f, f', f'' = force of the particles in a unity of section at (AB), (ab), and $(a'b')$ respectively;
$f_{,}, f_{,,}$ = „ „ $(A_{,}B_{,})$, and $(a_{,}b_{,})$.

1st. To find the moments of resistance of thesides (NA) and (OB) to compression, these sides being considered as thin incompressible joists.

We have $\frac{fsa^2}{3}$ = moment of resistance of the side (AN) from the neutral line (NO),

and $\frac{fsa^2}{3}$ = „ „ (BO) „ (NO);

$\therefore \frac{2}{3}fsa^2$ = moments of resistance of both sides (AN) and (BO) to compression. . . . . (A).

2nd. To find the moment of resistance of the vertical plates in the cells between (Aa'), and (Bb') to compression.

Since the moment of the forces of a rectangular body, considered as a thin incompressible joist, whose breadth is s' and depth a, extending from the top to the neutral line, would be $\frac{fs'a^2}{3}$, we have

$\frac{fs'a^2}{3} - \frac{f''s'(a-2c)^2}{3}$ = the moment of resistance of the vertical plates between (Aa') and (Bb').

But $f : f'' :: a : a - 2c$, $\therefore f'' = \frac{f(a-2c}{a}$.

Substituting this value in the formula for the moments given above, we have,

$$\frac{f s' a^2}{3} - \frac{f' s' (a-2c)^2}{3} = \frac{f s' a^2}{3} - \frac{f s' (a-2c)^2}{3a}$$

$$= \frac{f s'}{3}\left(a^2 - \frac{a^3 - 6a^2 c + 12 a c^2 - 8 c^3}{a}\right) = \frac{2 f s' c}{3}\left(3a - 6c + \frac{4c^2}{a}\right) \quad (B),$$

for the moments of resistance of the vertical plates between $(A\,a')$ and $(B\,b')$ to compression; these plates being considered as passing through and across the horizontal ones.

3rd. To find the moments of the forces of compression exerted by the horizontal plates $(A\,B)$, $(a\,b)$, and $(a'\,b')$, considered as reduced in length by the breadth of the vertical ones.

$t\,(b - 2s - s') =$ area of the section of $(A\,B)$,

$\therefore f t\,(b - 2s - s') =$ the force of all the fibres in $(A\,B)$,

and $f t a\,(b - 2s - s') =$ the moment of resistance of the particles in $(A\,B)$.

In like manner, we have

$f' t'\,(a-c)\,(b-2s-s') =$ moment of resistance of the particles in $(a\ b)$,

$f'' t''\,(a-2c)\,(b-2s-s') =$ „ „ „ $(a'\ b')$.

Putting $(b - 2s - s') = b'$, $f' = \frac{f(a-c)}{a}$, and $f'' = \frac{f(a-2c)}{a}$, we shall have

$$f t a b' = \text{moment in } (A\,B),$$

$$f t' \frac{(a-c)^2}{a} b' = \text{moment in } (a\ b),$$

$$f t'' \frac{(a-2c)^2}{a} b' = \text{moment in } (a'\ b').$$

Consequently, we shall have

$$f b'\left(t a + \frac{t'(a-c)^2}{a} + \frac{t''(a-2c)^2}{a}\right) = \text{moments of resistance in } (A\,B),\ (a\ b) \text{ and } (a'\ b') \quad (C).$$

Collecting the moments in (A), (B), and (C), we have

$$\frac{2}{3} f s a^2 + \frac{2}{3} f s, c\left(3a - 6c + \frac{4c^2}{a}\right) + f b'\left(t a + \frac{t'(a-c)^2}{a} + \frac{t''(a-2c)^2}{a}\right)$$

$=$ the sum of the moments of the compressed particles . . . (D).

Cor.—If the plates which are horizontal be equal in thickness, or $t = t' = t''$, equation (D) will become,

$$\frac{2}{3} f s a^2 + \frac{2}{3} f s' c \left(3a - 6c + \frac{4c^2}{a}\right) + f b' t \left(3a - 6c + \frac{5c^2}{a}\right) = \text{moment of compressed particles} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (E).$$

To find the moments of the forces of tension, we have, as in the cases of compression,

1st. For the moments of resistance of the sides $(N A_1)$, $(O B_1)$,

$\frac{2}{3} f_1 s a_1^2 =$ moment of resistances of the particles in $(N A_1)$ and $(O B_1)$, to tension . . . . . (F).

2nd. For the moments of the forces, exerted by the vertical plates in the cells between (A, a_1) and (B, b_1),

$$\frac{1}{3} f_1 s_1 a_1^2 - \frac{f_{11} s_1}{3} (a_1 - c_1)^2 = \text{moment of resistances of vertical plates}$$

between (A, a_1) and (B, b_1), considered as parts of incompressible joists, of which the depth, if they were complete, would be $(N A_1)$, $(O B_1)$.

$$\text{But } f_{11} : f_1 :: a_1 - c_1 : a_1 \qquad \therefore f_{11} = \frac{f_1 (a_1 - c_1)}{a_1};$$

Consequently, we shall have,

$$\frac{1}{3} f_1 s_1 a_1^2 - \frac{1}{3} f_{11} s_1 (a_1 - c_1)^2 = \frac{1}{3} f_1 s_1 a_1^2 - \frac{1}{3} f_1 s_1 \frac{(a_1 - c_1)^3}{a_1} =$$

$$\frac{1}{3} f_1 s_1 a_1^2 - \frac{1}{3} f_1 s_1 \left(\frac{a_1^3 - 3 a_1^2 c_1 + 3 a_1 c_1^2 - c_1^3}{a_1}\right)$$

$$= \frac{1}{3} f_1 s_1 \left(a_1^2 - a_1^2 + 3 a_1 c_1 - 3 c_1^2 + \frac{c_1^3}{a_1}\right) = \frac{1}{3} f_1 s_1 c_1 \left(3 a_1 - 3 c_1 + \frac{c_1^2}{a_1}\right)$$

= the moments of forces between (A, a_1) and (B, b_1) . . . . $(G.)$

3rd. For the moments of the horizontal plates (A, B_1), (a, b_1),

$t, (b - 2s - s_1) =$ area of section of the horizontal plate (A, B_1),

$f, t, a, (b - 2s - s_1) =$ moment of resistance of its particles.

Similarly,

$f_{11} t_{11} (a_1 - c_1) (b - 2s - s_1) =$ moment of resistance of the particles in (a, b_1).

But $f_{11} = \frac{f_1 (a_1 - c_1)}{a_1}$; and if we put $(b - 2s - s_1) = b_1$, we shall have,

$f_1 t, a, b, =$ moment of force in (A, B_1),

$\frac{f_1 t_{11} (a_1 - c_1)^2 b_1}{a_1} =$ moment of force in $(a\ b.)$

Therefore,

$$f, t, a, b, + \frac{f, t_{,,} b, (a, - c)^2}{a,} = f, b, \left\{ t, a, + t_{,,} \left(a, - 2\, c, + \frac{c,^2}{a,} \right) \right\} = \text{the sum}$$

of the moments of forces in $(A, B,)$ and $(a, b,)$ . . . $(H.)$

Adding together the moments in (F), (G), and (H), we have,

$$\frac{2}{3} f, s a,^2 + \frac{1}{3} f, s, c, \left(3\, a, - 3\, c, + \frac{c,^2}{a,} \right) + f, b, \left\{ t, a, + t_{,,} \left(a, - 2 c, + \frac{c,^2}{a,} \right) \right\}$$

= the whole of the moments of extension . . . . . (I).

The coefficient $f,$ in the preceding equation, represents the force in a unity of section, at the bottom of the tube; and to obtain it in terms of f, used in the equations of compression, we have,

$f : f, :: a : a, \quad \therefore f, = \frac{f a,}{a}$, consequently equation (I) becomes,

$$\frac{f a,}{a} \left\{ \frac{2}{3} s a,^2 + \frac{1}{3} s, c, \left(3\, a, - 3\, c, + \frac{c,^2}{a,} \right) + b, \left(t, a, + t_{,,} (a, - 2 c, + \frac{c,^2}{a,}) \right) \right\}$$

= moment of resistances to extension . . . . . (K).

Cor.—If $t, = t_{,,}$ the equation (K) will become,

$$\frac{f a,}{a} \left\{ \frac{2}{3} s a,^2 + \frac{1}{3} s, c, \left(3\, a, - 3 c, + \frac{c,^2}{a,} \right) + t, b, \left(2\, a, - 2\, c, + \frac{c,^2}{a,} \right) \right\} = \text{mo-}$$

ments of resistances to extension . . . . . (L).

The moments in (D) and (K), or their corollaries, being those of the whole section, we have,

$$\frac{l W}{4} = \text{moment in } (D) + \text{moment in } (K);$$

where l is the length, or distance of tube between the supports, and W the weight in the middle; for the moment of the forces caused by the weight is $\frac{l}{2} \times \frac{W}{2} = \frac{l W}{4}$, since a beam, supported at the ends, and loaded in the middle, may be considered as strained by half the weight W, acting at the ends, with a leverage of half the distance l, between the supports.

Computations from the preceding formulæ, applied to the Conway Tube, as first proposed to be made; the data being made on drawings supplied by Mr. Stephenson, 17th December, 1846.

In this tube, the form was that in the figure annexed to the foregoing problem; and the dimensions, and other data, were as below, the former notation being used.

The distance of the neutral line, from the bottom of the top cells, having been found, from the first problem, to be 101·23 inches, we have,

$a = (AN) = (Na') + (a'A) = 101{\cdot}23 + 37{\cdot}5 = 138{\cdot}73$ inches, the distance of the neutral line from the top of the tube;

$a_{,} = (A,N) = 180{\cdot}145$ inches, the distance of the neutral line from the bottom of (AB);

$(a'N) = 101{\cdot}23$ inches, „ „ „ (ab);

$(a,N) = 157{\cdot}645$ inches, „ „ top of $(a,b,)$;

$b = \ldots\ldots 169{\cdot}$ inches, the whole breadth;

$c = 18$ inches, the depth of each cell in the top, or 18·5 inches to the centres of the plates;

$c_{,} = 21$ inches „ in the bottom, or 21·75 inches to the centres of the plates, $t, t', t'', t_{,,}$ each $\frac{1}{2}$ inch thick;

$t_{,} = 1$ inch thick;

$s = \frac{1}{2}$ „

$s' = 4$ „

$s_{,} = 2\frac{1}{2}$ „

From formula (E) we have, for the moments of the compressed particles,

$$\left\{\frac{2}{2}s a^2 + \frac{2}{3}s'c\left(3a - 6c + \frac{4c^2}{a}\right) + b' t\left(3a - 6c + \frac{5c^2}{a}\right)\right\}f =$$

$$\left\{\frac{(138{\cdot}73)^2}{3} + \frac{2}{3} \times 4 \times 18{\cdot}5\left(3 \times 138{\cdot}73 - 6 \times 18{\cdot}5 + \frac{4 \times (18{\cdot}5)^2}{138{\cdot}73}\right)\right.$$

$$\left. + \frac{164}{2}\left(3 \times 138{\cdot}73 - 6 \times 18{\cdot}5 + \frac{5 \times (18{\cdot}5)^2}{138{\cdot}73}\right)\right\} f$$

$$= \left(6415{\cdot}338 + 49{\cdot}3(416{\cdot}19 - 111 + 9{\cdot}147) + 82(416{\cdot}19 - 111 + 12{\cdot}335)\right) f$$

$$= \left(6415{\cdot}338 + 15496{\cdot}814 + 26037{\cdot}05\right) f = 47949{\cdot}2 \times f \ldots.$$

the moments of compression.

From formula (K) we obtain, in like manner, the moments of the extended particles,

$$\frac{a_{,}}{a}\left\{\frac{2}{3}s a_{,}^2 + \frac{s_{,}c_{,}}{3}\left(3a_{,} - 3c_{,} + \frac{c_{,}^2}{a_{,}}\right) + b_{,}\left(t_{,}a_{,} + t_{,,}(a_{,} - 2c_{,} + \frac{c_{,}^2}{a_{,}})\right)\right\} f$$

$$= \frac{180{\cdot}145}{138{\cdot}73}\left\{\frac{1}{3} \times (180{\cdot}145)^2 + \frac{5 \times 21{\cdot}75}{2 \times 3}\left(3 \times 180{\cdot}145 - 65{\cdot}25\right.\right.$$

$$\left.\left. + \frac{(21{\cdot}75)^2}{180{\cdot}145}\right) + 165{\cdot}5\left(180{\cdot}145 + \frac{1}{2}(180{\cdot}145 - 43{\cdot}5 + \frac{(21{\cdot}75)^2}{180{\cdot}145})\right)\right\} f$$

$$= \frac{180{\cdot}145}{138{\cdot}73}\left\{10817{\cdot}407 + 18{\cdot}125\,(540{\cdot}435 - 65{\cdot}25 + 2{\cdot}626)\right.$$

$$\left. + 165{\cdot}5\,(180{\cdot}145 + 60{\cdot}635)\right\} f = \frac{180{\cdot}145}{138{\cdot}73}\left\{10817{\cdot}407 + 8660{\cdot}324\right.$$

$+ 41338{\cdot}59\Big\}f = \frac{180{\cdot}145}{138{\cdot}73} \times 60816{\cdot}321 \times f = 79000{\cdot}4 \times f$ . . . the moments of extension,

$\therefore 47949{\cdot}2 \times f + 79000{\cdot}4 \times f = 126949{\cdot}6 \times f$ . . . . the sum of the moments of the plates, neglecting the angle irons.

If these moments are equated to the value $\frac{l\,w}{4}$, found in the last article, we shall have,

$$\frac{l\,w}{4} = 126949{\cdot}6 \times f, \text{ or } w = \frac{(507798{\cdot}4)f}{l}.$$

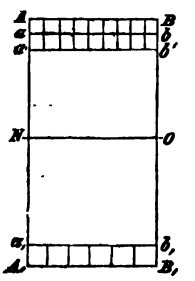
The distance between the supports in the proposed Conway Tube, is 400 feet, therefore $l = 400$ feet $= 4800$ inches, and $f =$ the force of compression in a square inch of section at the top of the tube.

Problem 3.

Another computation of the moments, to obtain the strength of the proposed Tubular Bridge, across the river at Conway.

The figure in the margin being supposed to represent a section of the tube in the middle, and $(N\,O)$ the neutral line; we have, as below, taking the dimensions from the drawings supplied.

From the previous investigation, as to the situation of the neutral line (Prob. 1), it appears that the distance $(a'\,N)$, in the case of this problem, is 101·23 inches. Whence we have,



$a = (A\,N) = 101{\cdot}23 + 37{\cdot}5 = 138{\cdot}73$ inches, the distance of the neutral line from the top;

$a_{,} = (A_{,}N) = 180{\cdot}145$ inches, the distance of the neutral line from the bottom of $(A,B_{,})$;

$(a,N) = 101{\cdot}23$ inches, the distance of the neutral line from the bottom of $(a'\,b')$;

$(a,N) = 157{\cdot}645$ inches, the distance of the neutral line from the top of $(a,b_{,})$;

$b = 169$ inches, the whole external breadth;

$c = 18$ inches, the distance between $(A\,B)$ and $(a\,b)$, or $(a\,b)$ and $(a'\,b')$;

$c_{,} = 21$ inches, the distance between $(A,B_{,})$ and $(a,b_{,})$;

$t = \frac{1}{2}$ inch, the thickness of plate $(A\,B)$;

$t' = \frac{1}{2}$ " " $(a\,b)$;

$t'' = \frac{1}{2}$ " " $(a'\,b')$;

$t_{,} = 1$ " " $(A,B_{,})$;

$t_{,,} = \frac{1}{2}$ " " $(a,b_{,})$;

$s = 1$ " " $(a'\,a_{,})$ and $(b'\,b_{,})$;

$s'=$ 5 inches, the thickness of vertical plates between ($A\,B$) and ($a'\,b'$) including the sides opposite to them;

$s_{,}=$ $3\frac{1}{2}$ inches, the thickness of vertical plates between ($A_{,}\,B_{,}$) and ($a_{,}\,b_{,}$) including the sides opposite to them.

Now, if f be the force exerted by the particles in a unity of section, at a unity of distance from the neutral line, we shall have,

$f \times a =$ force of the particles in a unity of section at the top of ($A\,B$);

$f\left(a-\frac{t}{2}\right)=$ " " " centre of ($A\,B$);

$f\left(a-c-t-\frac{t'}{2}\right)=$ " " " ($a\,b$);

$f\left(a-2c-t-t'-\frac{t''}{2}\right)=$ " " " ($a'\,b'$);

$f \times 101{\cdot}23 =$ " " " bottom of ($a'\,b'$);

$f \times 157{\cdot}645 =$ " " " top of ($a_{,}\,b_{,}$);

$f \times \left(157{\cdot}645 + \frac{t_{,,}}{2}\right)=$ " " centre of ($a_{,}\,b_{,}$);

$f \times a_{,}=$ " " " bottom of ($A_{,}\,B_{,}$);

$f\left(a_{,}-\frac{t'}{2}\right)=$ " " " centre of ($A_{,}\,B_{,}$);

The values above, expressed in numbers, will become,

$f \times a = f \times 138{\cdot}73 =$ force at top of ($A\,B$);

$f\left(a-\frac{t}{2}\right) = f \times 138{\cdot}48 =$ force at centre of ($A\,B$);

$f\left(a-c-t-\frac{t'}{2}\right) = f \times 119{\cdot}98 =$ force at centre of ($a\,b$);

$f\left(a-2c-t-t'-\frac{t''}{2}\right) = f \times 101{\cdot}48 =$ force at centre of ($a'\,b'$);

f (distance $N\,a'$) $= f \times 101{\cdot}23 =$ force at bottom of ($a'\,b'$);
f (distance $N\,a_{,}$) $= f \times 157{\cdot}645 =$ force at top of ($a_{,}\,b_{,}$);
$f \times 157{\cdot}895 =$ force at centre of ($a_{,}\,b_{,}$);
$f\,a_{,} = f \times 180{\cdot}145 =$ force at bottom of ($A_{,}\,B_{,}$);

$f\left(a_{,}-\frac{t_{,}}{2}\right) = f \times 179{\cdot}645 =$ force of centre of $A_{,}\,B_{,}$).

Moments of the Forces of the Plates, and Angle Irons, in the Tube.

1st. To find the moments of the forces of the plates composing the sides.

If we consider the sides of the tube, above and below the neutral line, as incompressible joists, the breadth of which is s, and the depth (a' N) or (N $a_{,}$), according as they are on the compressed or extended side of the neutral line, we shall have, in the former case, the moment of the forces of the compressed sides equal to the force of a particle at the distance of (a' b') × the breadth of the sides, and by one-third of the square of the depth (N $a_{,}$).

Whence,

$$f \times 101{\cdot}23 \times s \times \frac{(101{\cdot}23)^2}{3} = f \times \frac{(101{\cdot}23)^3}{3} = 345785 \times f \text{ . (1)},$$

the moment of compressed sides (a' N) and (b' O), between the neutral line and the cellular part.

Similarly, we have,

$$f \times 157{\cdot}645 \times s \times \frac{(157{\cdot}645)^2}{3} = f \times \frac{(157{\cdot}645)^3}{3} = 1305928 \times f \text{ . (2)},$$

the moments of the extended sides (a, N) and (b, O),

$$\therefore 345785 \times f + 1305928 \times f = 1651713 \times f \quad . \quad . \quad . \quad . \quad . \quad (A),$$

the sum of the moments of the sides (a' $a_{,}$) and (b' $b_{,}$), not including those of the cells above and below the neutral line.

2nd. To find the moment of the forces of the vertical plates between (A B) and (a' b'), including that of the sides (A a') and (B b').

$$f \times 138{\cdot}73 \times s' \times \frac{(138{\cdot}73)^2}{3} = f \times \frac{5}{3} \times (138{\cdot}73)^3 = 4449998 f \quad (1),$$

the moments of the vertical plates, supposing them to extend down to the line (N O),

$$\therefore f \times 101{\cdot}23 \times 5 \times \frac{(101{\cdot}23)^2}{3} = f \times \frac{5}{3} \times (101{\cdot}23)^3 = 1728925 f \quad (2),$$

the moments of the vertical plates from (a' b') to (N O).

Subtracting the value in (2) from that in (1), we have,

$$4449998 f - 1728925 f = 2721073 f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3),$$

the moments of the vertical compressed plates between (A B) and (a' b').

In like manner, for the extended plates, we have,

$$f \times 180{\cdot}145 \times s_{,} \frac{(180{\cdot}145)^2}{3} = f \times \frac{7}{6} \times (180{\cdot}145)^3 = 6820456 f \quad (4),$$

the moments of the forces of the vertical plates; supposing them to extend from the bottom, to the neutral line.

$\therefore f \times 157{\cdot}645 \times s, \times \frac{(157{\cdot}645)^2}{3} = f \times \frac{7}{6} \times (157{\cdot}645)^2 = 4570749f$ (5),

the moments of the vertical plates from $(a, b,)$ to $(N\ O)$.

Deducting the value in (5) from that in (4), we have,

$$6820456f - 4570749f = 2249707f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6),$$

the moments of the vertical plates between $(a, b,)$ and $(A, B,)$.

Adding the values in (3) and (6) together, we shall have,

$$2721073f + 2249707f = 4970780f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (B),$$

the sum of the moments of the forces of the vertical plates.

3rd. To find the moments of the forces of the horizontal plates $(A\ B)$, $(a\ b)$, $(a'\ b')$, $(a, b,)$ and $(A, B,)$; beginning with those at the top, or the compressed ones; and putting b', for the whole breadth b, of the tube — the thickness of the vertical plates, or $169 - 5 = 164$, we have,

$$f \times 138{\cdot}48 \times t\,b' \times 138{\cdot}48 = f \times (138{\cdot}48)^2 \times \frac{164}{2} = 1572490f \quad . \quad (1),$$

the moment of the horizontal plate $(A\ B)$.

$$\therefore f \times 119{\cdot}98 \times t\ b' \times 119{\cdot}98 = f \times (119{\cdot}98)^2 \times \frac{164}{2} = 1180406f \quad . \quad (2),$$

the moment of the horizontal plate $(a\ b)$.

$$\therefore f \times 101{\cdot}48 \times t\ b' \times 101{\cdot}48 = f \times (101{\cdot}48)^2 \times \frac{164}{2} = 844452f \quad . \quad (3),$$

the moment of the horizontal plate $(a'\ b')$.

Adding together the values in (1), (2), and (3), we shall have

$$1572490f + 1180406f + 844452f = 3597348f \quad . \quad . \quad . \quad (4),$$

the moments of the forces of compression of the horizontal plates $(A\ B)$, $(a\ b)$, and $(a'\ b')$.

Again, for the moments of extension of the horizontal plates; putting b'' for the whole breadth, b, of the tube — the thickness of the vertical plates; or $169 - 3{\cdot}5 = 165{\cdot}5$, we have,

$$f \times 179{\cdot}645 \times t,\ b'' \times 179{\cdot}645 = f \times (179{\cdot}645)^2 \times 165{\cdot}5 = 5341070f \quad (5),$$

the moments of the horizontal plate $(A, B,)$.

$$\therefore f \times 157{\cdot}895 \times t,, b'' \times 157{\cdot}895 = f \times (157{\cdot}895)^2 \times \frac{165{\cdot}5}{2} = 2063026f \quad (6),$$

the moments of the horizontal plate $(a, b,)$.

The sum of the moments in (5) and (6) gives

$$5341070f + 2063026f = 7404096f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7),$$

the moments of the forces of extension in the horizontal plates $(a, b_,)$ and $(A, B_,)$.

Collecting the moments in (4) and (7), we shall have,

$$3597348f + 7404096f = 11001444f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (C),$$

the moments of the forces in the horizontal plates $(A\,B)$, $(a\,b)$, $(a'\,b')$, and $(a, b_,)$, $(A, B_,)$.

The sum of the moments in (A), (B), and (C) contains those of the forces of resistance to compression and extension in all the plates in the section, the force of the angle irons being neglected.

$\therefore$ $1651713 \times f + 4970780 \times f + 11001444 \times f = 17623937f =$ sum of moments from all the plates . . . . . (D),

Comparing the moments of the plates, as obtained from the former problem, we have $126949{\cdot}6 \times f \times 138{\cdot}73 = 17611718 \times f$, differing not widely from that above.

2nd. *Moments of Resistance of the Angle Irons in the top and bottom cells of the Tube.*

Retaining the same notation, we have, according to the plan proposed,

$a - t$ $= 138{\cdot}73 - {\cdot}5 = 138{\cdot}23$ ins. = distance from the neutral line to the angle irons in $(A\,B)$;

$a - \left(c + t + \frac{t'}{2}\right) = 138{\cdot}73 - 18{\cdot}75 = 119{\cdot}98$ ins. = „ $(a\,b)$;

$a - (2c + t + t') = 138{\cdot}73 - 37{\cdot} = 101{\cdot}73$ ins. = „ $(a'\,b')$;

$a_, - (c_, + t_,) = 180{\cdot}145 - 22{\cdot} = 158{\cdot}145$ ins. = „ $(a, b_,)$;

$a_, - t_, = 180{\cdot}145 - 1{\cdot} = 179{\cdot}145$ ins. = „ $(A, B_,)$.

Area of section of angle irons in $(A\,B) = 20 \times 2{\cdot}5 = 50$ square inches.

„ „ $(a\,b) = 36 \times 2{\cdot}5 = 90$ „

„ „ $(a'\,b') = 24 \times 2{\cdot}5 = 60$ „

„ „ $(a, b_,) = 18 \times 2{\cdot}5 = 45$ „

„ „ $(A, B_,) = 14 \times 2{\cdot}5 = 35$ „

We have, therefore, moment of forces of angle irons in $(A\,B) = (a - t)\,f \times 50 \times (a - t) = 50f \times (a - t)^2 = 50f \times (138{\cdot}23)^2 = 955376f =$ moment of forces of angle irons in $(A\,B)$.

In like manner, we have, for the moments of the forces of the angle irons in the other plates, as below,

$$\text{In } (a\ b);\ \left(a-(c+t+\tfrac{t'}{2})\right)f\times 90\times\left(a-(c+t+\tfrac{t'}{2})\right)=$$

$$90f\times\left(a-(c+t+\tfrac{t'}{2})\right)^2=90f\times(119{\cdot}98)^2=1295568f.$$

In $(a'\ b')$;	moment	$=60f\times(101{\cdot}73)^2=620939f.$
In $(a_,\ b_,)$;	„	$=45f\times(158{\cdot}145)^2=1125442f.$
In $(A_,\ B_,)$;	„	$=35f\times(179{\cdot}145)^2=1123252f.$

Collecting together the first three moments, gives

$$955376f+1295568f+620939f=2871883f,$$

for those of the compressed angle irons in top of tube.

And the sum of the last two moments, gives

$$1125442f+1123252f=2248694f,$$

for the moments of the forces of the angle irons submitted to tension.

The sum of the moments of all the forces from the plates and angle irons is, therefore,

Moments from the plates, see (D)	17,623,937 f.
„ angle irons (compression) .	2,871,883 f.
„ „ (extension) . .	2,248,694 f.
Moments from the whole	22,744,514 f. (A).

If the moments from the angle irons, submitted to tension, be omitted, the neutral line being assumed to remain unchanged, we have the moments above,

$$=17{,}623{,}937f+2{,}871{,}883f=20{,}495{,}820f \quad . \ . \ . \ . \ (B).$$

The angle irons in the lower part of the tube will not act with their whole tensile force, on account of the defective connections at their ends; if, therefore, their moments be taken at one half their assigned value, or $\frac{2248694}{2}=1124347$, we shall have the moment of the whole,

$$=17{,}623{,}937f+2{,}871{,}883f+1{,}124{,}347f=21{,}620{,}167f.\ (C).$$

Computation of the Strength of the Tube from the preceding Moments.

The sum of the moments of the forces in the section of the tube must, from the equilibrium of the forces acting upon it, be equal to the

product of half the distance between the supports by half the weight, considered as laid on the middle of the tube.

Putting then, $m f =$ the moment of the forces in the section of the tube, we have

$$m f = \frac{l}{2} \times \frac{w}{2} = \frac{l w}{4}, \quad \therefore w = \frac{4 m f}{l}.$$

The distance between the supports in the proposed bridge at Conway is 400 feet, therefore, $l = 400$ feet $= 4800$ inches; and from (A) (last page), $m = 22744514 f$; we have, likewise, f, a number such (p. 70) that $f a =$ force per unity of section, sustained by the material at distance ($A N$) from the neutral line.

$$\therefore w = \frac{4 m f}{l} = \frac{4 \times 22744514 f}{4800} = \frac{22744514 f}{1200} = 18953{\cdot}7 f.$$

If $f a$, the compressive force per square inch at the top ($A B$), be 8 tons, then $f a = 8$; and since

$a = 138{\cdot}73$ ins. (p. 69), we shall have $f = \frac{8}{a} = \frac{8}{138{\cdot}73} = {\cdot}05767.$

Whence,

$$w = 18953{\cdot}7 f = 18953{\cdot}7 \times {\cdot}05767 = 1093 \text{ tons.}$$

If the moments from the tensile forces of the angle irons be neglected, we shall have from (B) the moment of the remainder $= 20495814 f$.

$$\therefore w = \frac{4 \times 20495820 f}{4800} = \frac{204958{\cdot}20 f}{12} = 17079{\cdot}8 f = 17079{\cdot}8 \times {\cdot}05767$$

$= 984{\cdot}99$ tons, for a pressure of 8 tons per square inch, at the top.

The *tensile* force of the angle irons ought not to be wholly neglected; and if we suppose these irons acting with half their full tensile power, we shall have, from (C), $21620167 f$ for the moment of the whole forces in the section.

$$\text{Whence, } w = \frac{4 \times 21620167 f}{4800} = \frac{216201{\cdot}67 f}{12}$$

$$= 18016{\cdot}8 f = 18016{\cdot}8 \times {\cdot}05767 = 1039{\cdot} \text{ tons.}$$

This load, including the pressure from the weight of the tube, would, as before, produce a pressure of 8 tons per square inch on the top. But the tensile strain at the bottom of the tube would be greater than this in the ratio of the distances of the neutral line from the bottom and top of the tube; or as $180{\cdot}145 f$, to $138{\cdot}73 f$, these being the forces per square inch at the bottom and top.

Whence $\frac{8 \times 180{\cdot}145}{138{\cdot}73} = 10{\cdot}388$ tons, the simultaneous strain at the bottom.

The load above seems to be the greatest that the tube ought to be made to bear; but if it were loaded to the extent of 12 tons per square inch at the top, then from the position of the neutral line, the material would be strained to the extent of 15·57 tons per square inch at the bottom; and the load which the tube would then have to sustain, including that from its own weight, would be

$$\frac{12 \times 1038{\cdot}8}{8} = 1558{\cdot}2 \text{ tons.}$$

This weight, including the pressure from the weight of the tube might, it is probable, be borne by a tube of these dimensions, without absolutely destroying the utility of the material.

But this would depend on the following suppositions: that the weight was laid on gradually; that no vibration took place in the tube, and that the tube had no joints, by which the tenacity of the metal could be weakened. With respect to the latter supposition, the necessity of using plates riveted together causes a great falling off in the strength.

From experiments which I made for Mr. Fairbairn to ascertain the best modes of riveting (see Reports of British Association), I was led to conclude that riveted plates could not be made to bear more than two-thirds of the weight which plates without joints would bear.

As all the reasonings in this paper are from tubes formed of plates without joints, I consider the weight above as hypothetical, and much greater than the tube should ever be strained with.

The question as to the strength of the tube is here considered as a statical one, but this is not strictly, nor perhaps nearly, the case; a train, rushing into a tube, which was previously bent only by its own weight, may be expected to deflect it more than the same weight laid on gradually.

Preparatory to seeking for the deflection of the tube, the following experimental results, which will be made use of, may be given.

Longitudinal Compression of four Wrought-Iron Bars, prevented from flexure by a frame in which they were enclosed.

The bars in these experiments were each 10 feet long and 1 inch square nearly, and the weights given below were, in appearance, the utmost the material would bear without its practical utility being destroyed.

Weights laid on.	Decrements of Length, with Load.
Lbs.	Inch.
26486·	·138
26486·	·132
27380·	·144
27380·	·143
4)107732·	·557
26933· lbs. = 12·02 tons.	·139

The length of the bar being 10 feet, or 120 inches, we have $\frac{120}{\cdot 139} = 863$.

Hence, a wrought-iron bar will bear a compression of $\frac{1}{863}$rd of its length, without its utility being destroyed, though it will have sustained a considerable change in its elastic force with less than that compression.

If we multiply the mean weight laid on by 863, we have $26933 \times 863 = 23243179$ lbs. $= E$, the force which, if tensile, would increase the bar to double its length, supposing the elasticity to remain perfect.

Compression of Tubes with Joints in them.

In the experiments on the compression of tubes with joints, as in the top of the proposed tubular bridge, I sometimes found that a tube 10 feet long was decreased ·2 inch or upwards, by a weight of 12 tons per square inch. But $\frac{120}{\cdot 2} = 600$; the tube would therefore be decreased by $\frac{1}{600}$th of its length.

Modulus of Elasticity of Wrought Iron.

I found the Modulus of Elasticity, or that weight which (the elasticity being supposed to remain perfect) would draw a bar 1 inch square to double its length: the modes I used were different, but the results were not widely so. From experiments drawn from the longitudinal tension of bodies, it was 23865624 lbs. per square inch. From others it was 24446394 lbs.; and from the preceding experiments on compression, it was 23243179 lbs.; the mean from these three is 23851732 lbs. The modulus, according to Tredgold, obtained in a different way, is 24920000 lbs. It will, in the future computations, be taken at 24000000 lbs. = 10714·3 tons per square inch, and this value will be called E *.

* The modulus of elasticity of annealed wrought iron, from experiments upon the extension of bars 50 feet long, was 27,691,200 lbs.

Radius of Curvature of the Centre of the Conway Tube in the middle, or place of greatest flexure.

It appears, from the preceding experiments, that a bar of wrought iron will be compressed $\frac{1}{863}$rd of its length, without destroying its utility. Hence, wherever the neutral line of the bent tube may be, its concave side at the part of greatest strain may be reduced in the ratio of 863 to 862.

Let ρ be the radius of curvature of the neutral line, and a the distance of the concave side from that line, then $\rho - a$ will be the radius of curvature of the concave side, the distance of which from the neutral line is a.

We shall then have (as in the next figure),

$$\rho : \rho - a :: 863 : 862;$$

whence $862\,\rho = 863\,\rho - 863\,a$, $\therefore \rho = 863\,a$.

In the proposed tube $a = 138{\cdot}73$ inches (Problem 3, page 168),

$$\therefore \rho = 863 \times 138{\cdot}73 = 119723{\cdot}99 \text{ inches} = 9977 \text{ feet.}$$

Whence the radius of curvature of the tube, when bent to the utmost it will bear, without destroying the utility of the metal by compression, is 9977 feet = 1·9 mile, nearly; and the force exerted by the particles, contracted by $\frac{1}{863}$rd of their length, is 26933 lbs., or 12 tons per square inch nearly.

To find the connexion between the Radius of Curvature, and the value of f, previously employed.

The figure annexed being supposed to represent the tube when bent,

Put ρ = ($A\,O$) the radius of curvature of the neutral line;

a = ($B\,C$) the distance of the neutral line from the concave side;

e = ($A\,B$) any small portion of the length of the neutral line;

e' = ($C\,D$) the decrement of the concave side, answering to the part ($A\,B$);

E = the force necessary to elongate or shorten a bar of wrought iron, 1 inch square, by a quantity equal to the length e of the bar, = 24,000,000 lbs. = 10714·3 tons;

fa = the force per square inch necessary to produce the compression e'.

The line ($B\,C$) being drawn parallel to ($A\,O$), we have from similar triangles,

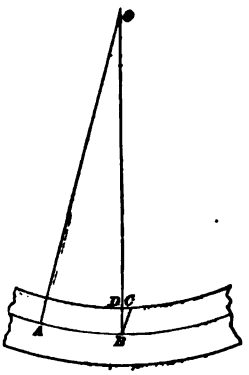
$(A\,O) : (B\,C) :: (A\,B) : (C\,D)$, or

$\rho : a :: e : e'$

But $e : e' :: E : fa$

Whence $E : fa :: \rho : a$,

$$\therefore \frac{E}{\rho} = \frac{fa}{a} = f,$$



We have therefore $\frac{E}{\rho} = f$, whatever the flexure of the tube may be.

To find the Deflexion of the Tube.

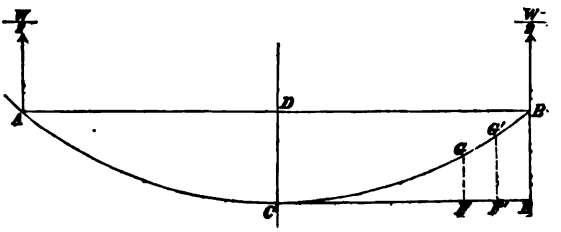
When a uniform beam, or other flexible body, is placed on supports at its ends, and loaded with a weight, w, in the middle, if $A\,C\,B$ represent the beam, the deflexion $C\,D$ will be the same as if the beam were fixed firmly in the middle, and drawn up by a weight $\frac{w}{2}$ at each end.

Let l = $(C\,E)$ = half the length of the beam, nearly;

x, y = the horizontal and vertical co-ordinates of any point G, in the curve, referred to C as the origin;

ρ = the radius of curvature at the point G;

δ = the distance $E\,B$, or whole deflexion $C\,D$.



Then, from above, we have $\frac{E}{\rho} = f$, whatever the value of f may be. But it was shown (A), (B), (C) (page 74), that the moment of the forces in the Conway Tube was mf, where m varied, according to different suppositions, between 22,744,508 and 20,495,814, and the mean 21,620,161, as in (C), was adopted.

But $mf = \frac{w}{2}(l - x)$; and since $f = \frac{E}{\rho}$, $m\,\frac{E}{\rho} = \frac{w}{2}(l - x)$.

But $\frac{1}{\rho} = \frac{\frac{d^2y}{dx^2}}{\left(1+\frac{dy^2}{dx^2}\right)^{\frac{3}{2}}}$, and when the deflexion is small, $\frac{dy^2}{dx^2}$ may be neglected, we shall then have,

$$\frac{1}{\rho} = \frac{d^2y}{dx^2}; \text{ and since } \frac{mE}{\rho} = \frac{w}{2}(l-x),$$

$$\therefore mE\frac{d^2y}{dx^2} = \frac{w}{2}(l-x).$$

Integrating $$mE\frac{dy}{dx} = \frac{w}{2}\left(lx - \frac{x^2}{2}\right)$$

„ $$mEy = \frac{w}{2}\left(\frac{lx^2}{2} - \frac{x^3}{6}\right).$$ When $x = l$, $y = \delta$;

$$\therefore mE\delta = \frac{w}{2} \times \frac{l^3}{3}, \qquad \delta = \frac{w\,l^3}{6mE},$$

where $m = 21{,}620{,}161$, and $E = 24{,}000{,}000$ lbs. $= 10714{\cdot}3$ tons.

If weight w be taken in tons; then,

$$\delta = \frac{w\,l^3}{6 \times 21620161 \times 10714{\cdot}3} = \frac{w\,l^3}{1{,}389{,}869{,}346{,}014}.$$

In the Conway Tube, $l = 200$ feet $= 2400$ inches;

$$\therefore \delta = \frac{w\,(2400)^3}{1{,}389{,}869{,}346{,}014} = \frac{w}{100{\cdot}540}.$$

1st. If $w = 1039{\cdot}$ tons, which would, from page 75, produce a pressure on the concave side, equal to 8 tons per square inch, the angle irons at bottom being supposed to act with half their tensile force, $\delta = \frac{w}{100{\cdot}54} = \frac{1039}{100{\cdot}54} = 10{\cdot}33$ inches $=$ the ordinate BE, at the end of the tube, or the deflexion CD, in the middle.

This deflexion is that which would accrue from the tube if it were made without joints, and was of small weight comparatively with the load in the middle. But the weight of the tube is great, and the riveted joints may be expected to adjust themselves with the strain, and increase the deflexion beyond the computed amount.

2nd. If $w = 1558{\cdot}2$ tons, the pressure which (from page 76) would strain the tube to 12 tons per square inch at the top, and 15·57 tons at the bottom.

Then $\delta = \frac{w}{100{\cdot}54} = \frac{1558{\cdot}2}{100{\cdot}54} = 15{\cdot}5$ inches nearly.

To determine a deflexion of a beam, caused by its own weight. It

has been shown by various writers, and might easily be demonstrated here, that when the ends are rested on supports, the deflexion of a uniform beam, from a weight uniformly distributed over its length, is to the deflexion from the same weight applied in the middle, as 5 to 8.—(*Tredgold, "Essay on Cast Iron," Art.* 62).

Deflexion of the proposed Tube from its own weight.

Suppose the tube to be uniform, and its weight, together with that of the platform within it, to be 900 tons, then the deflexion of the tube, in consequence of its weight, spread uniformly over it, would, from the last article, be

$$\delta = \frac{5}{8} \times \frac{w}{100{\cdot}54} = \frac{5 \times 900}{8 \times 100{\cdot}54} = 5{\cdot}59 \text{ inches},$$

or a little more in consequence of riveting. It would therefore appear that the deflexion from the weight of the tube is to the utmost deflexion which the tube could sustain without serious injury, as 5·59 to 15·5, or as 10 to 28 nearly. The computations on this first intended form of the Conway Tube were sent to Mr. Stephenson, through his talented assistant, Mr. Edwin Clark.

To find the deflexion of the tube from other principles, supposing the curve to be a portion of a parabola, or of a circle, and the curvature in the middle to be the greatest that the tube could sustain without destroying the utility of the material.

The radius of curvature was found (page 78) to be 9977 feet.

1st. Suppose the curve to be a parabola, of which the equation is $y^2 = 4mx$.

Then the deflexion $x = \frac{y^2}{4m}$.

In this curve, $2m$, the semi-parameter, is equal to the radius of curvature at the vertex.

But from above, $2m = 9977$ feet, and in the Conway Tube, $y = 200$ feet.

$$\therefore x = \frac{y^2}{4m} = \frac{(200)^2}{2 \times 9977} = 2{\cdot}00 \text{ feet} = 24 \text{ inches nearly.}$$

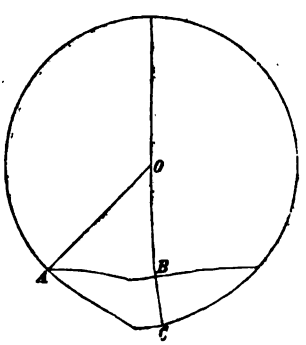
2nd. If the curve be a circular arc.

Then $\sqrt{(AO)^2 - (AB)^2} = (OB)$,

$(BC) = (CO) - (OB) = (AO) - (OB)$.

But $(AO) = 9977$ feet; $(AB) = 200$ feet.

$\therefore (BC) = 2{\cdot}01$ feet $= 24{\cdot}12$ inches.



Both of these curves, especially the circle, which is everywhere equally bent, must obviously give a larger deflexion, for the same length and curvature at C, than the proper curve of the tube, which is very little bent towards the ends. The relative deflexions of the tube, estimated as an elastic curve, and a circle, or parabola, are 15·5 inches, and 24 inches nearly.

In the preceding tube, the strength of the bottom would have been too small for the heavy cellular top, and the neutral line was much too high. I therefore suggested to Mr. Stephenson the desirableness of increasing the strength at the bottom. It was, however, thought better to dispense with one row of cells, and make the thickness of the plates stronger than before, to resist better the tendency to wrinkling; the preceding experiments on the longitudinal compression of rectangular tubes having shown that the resisting power increased nearly as the cube of the thickness. The form represented in Plate V. of the Report, Appendix A. A., was therefore fixed on, March, 1847, and I was requested to make the same computations upon it as before.

Problem 4.

To find the situation of the neutral line in the proposed tube, adopting the modes used in the preceding investigation.

In this tube, the cellular top is composed of two horizontal plates and nine vertical ones, including those on the sides opposite to the cells; and the thickness of the plates is $\frac{3}{4}$ inch each.

The whole width is 14 feet 1 inch; whence 14 feet 1 inch $\times$ 2 $=$ 28 feet 2 inches.

The depth of the vertical plates is 1 foot 9 inches; therefore, 1 foot 9 inches $\times$ 9 $=$ 15 feet 9 inches, the length of the vertical plates.

The whole length of the plates is therefore 28 feet 2 inches + 15 feet 9 inches $=$ 43 feet 11 inches $=$ 527 inches, and the area of their section $=$ 527 $\times$ $\frac{3}{4}$ $=$ 395·25 square inches, the whole area of the plates composing the top of the tube. These cells contain in their corners in addition 40 angle irons, the section of each of which is 4 inches; whence 40 $\times$ 4 $=$ 160 square inches, the area of their sections. There are, likewise, 16 longitudinal strips to cover the joints, the area of section of which is 16 $\times$ 9 $\times$ $\frac{1}{2}$ $=$ 72 square inches.

We have, therefore, 395·25 + 160 + 72 $=$ 627·25 square inches $=$ the whole area of section of the cells, which we will call A. The centre of gravity of this mass is very nearly in the middle.

The cellular bottom of the tube as proposed, is composed of two horizontal plates of 1 inch thick each, and seven vertical ones of $\frac{1}{2}$ inch thick each.

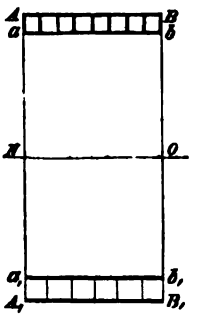
The length of the horizontal plates is 14 feet 1 inch $\times$ 2 $=$ 28 feet

2 inches = 338 inches, and their thickness being 1 inch, their area of section is 338 square inches.

The length of the vertical plates is 1 foot 9 inches × 7 = 12 feet 3 inches = 147 inches, and their thickness being $\frac{1}{2}$ inch, 147 × $\frac{1}{2}$ = 73·5 square inches. Whence, the area of the section of all the plates in these cells is 338 + 73·5 = 411·5 square inches.

In these cells there are likewise 32 angle irons, the area of section of which is 32 × $2\frac{1}{2}$ = 80 square inches. We have, therefore, 411·5 + 80 = 491·5 square inches, in the section of the plates and angle irons of the lower cells of the tube, and this area we will call $A_{,}$. The centre of gravity of this mass, like that of the other, is in its middle.

Suppose the annexed diagram to represent a section of the tube in the middle, and (NO) to be the neutral line.



Let us then put,

A = the area of the section of the cellular top (Ab) = 627·25 square inches;
= the area of the section of the bottom ($a, B_{,}$) = 491·5 square inches;

d = distance ($a\,a_{,}$) = 21 feet $6\frac{7}{8}$ inches = 258·875 inches;

c = half distance ($A\,a$) = $\frac{22{\cdot}5}{2}$ = 11·25 inches, the distance of centre of gravity of upper cells, from bottom of plate ($a\,b$);

$c_{,}$ = $\frac{23}{2}$ = 11·5 inches, the distance of centre of gravity of lower cells, from top of plate ($a,b_{,}$);

t = thickness of side ($a\,a_{,}$), or ($b\,b_{,}$) = $\frac{1}{2}$ inch;

x = (Na) the distance of the neutral line from the bottom of the top cells;

$x + c$ = distance of centre of gravity of A, from neutral line;

$d - x + c_{,}$ = " " $A_{,}$ "

$\frac{x}{2}$ = " " $2tx$ "

$\frac{d - x}{2}$ = " " $2(d - x)t$ "

The last two equations refer to the side plates, between the top and bottom cells.

Therefore, $(x + c)\,A$ = moment of the area A with respect to the neutral line;

$(d - x + c_{,})\,A_{,}$ = " " $A_{,}$ " "

tx^2 = " " $2tx$ " "

$t(d - x)^2$ = " " $2t(d - x)$ " "

Equating the moments, on the opposite sides of the neutral line, we have,

$$(x + c)\,A + tx^2 = (d - x + c,)\,A, + t\,(d - x)^2,$$

whence,
$$x = \frac{(d + c,)\,A, - c\,A + td^2}{A + A, + 2dt}.$$

Inserting in this equation the numerical values, gives

$$x = \frac{(258{\cdot}875 + 11{\cdot}5)\,491{\cdot}5 - 11{\cdot}25 \times 627{\cdot}25 + {\cdot}5\,(258{\cdot}875)^2}{627{\cdot}25 + 491{\cdot}5 + 2 \times 258{\cdot}875 \times {\cdot}5}$$

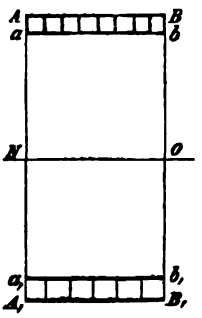
$$= 115{\cdot}66 \text{ inches.}$$

This computation has been made on the supposition that the angle irons acted with their whole force, both of tension and compression, in the same manner as the plates; but it is probable that the angle irons in the lower part of the tube would not act with their whole tensile force, as mentioned in the computation of the strength, according to the former supposition (December, 1846).

Problem 5.

Strength of the proposed Tube.

To find the moment of the forces, and the weight borne by the tube, we shall follow the reasoning used in the investigations on that previously proposed.



Since the top and bottom of the present tube are of the same form as the lower part in the former one (see page 69 of that inquiry), we may adopt the notation there employed, and the dimensions from the plan furnished by Mr. Stephenson, and referred to in the last problem. The distance (Na), from the neutral line to the bottom of (ab), is 115·66 inches, as determined in that problem, and the distance $(Na,)$, from the neutral line to the top of $(a,b,) = 258{\cdot}875 - 115{\cdot}66 = 143{\cdot}215$ inches.

This position of the neutral line will be supposed to remain unchanged, notwithstanding any change of supposition with respect to the action of the angle irons, since the effect of such a change would have very little influence on the strength.

We shall therefore assume—

$a = (NA) = (Na) + (aA) = 115{\cdot}66 + 22{\cdot}5 = 138{\cdot}16$ inches, the distance from the neutral line to the top of the tube;

$a_{,} = (NA_{,}) = (Na_{,}) + (a_{,}A_{,}) = 143{\cdot}215 + 23{\cdot} = 166{\cdot}215$ inches, the distance from the neutral line to the bottom of the tube;

$(AA_{,})$ the whole depth $= 304{\cdot}375$ inches $= 25{\cdot}3646$ feet;

$b = 169$ inches, the whole external breadth;

$c = 22{\cdot}5$ „ the whole depth of the top cells;

$c_{,} = 23{\cdot}$ „ „ „ bottom cells;

$t = {\cdot}75$ „ the thickness of the plate (AB) or of the plate (ab);

$t_{,} = 1$ inch, the thickness of the plate $(A_{,}B_{,})$, or of the plate $(a_{,}b_{,})$;

$s = 1$ „ the thickness of the side plates $(aa_{,})$ and $(bb_{,})$ taken together;

$s' = 6{\cdot}75$ inches the thickness of the vertical plates between (AB) and (ab), including the sides opposite to them;

$s_{,} = 3{\cdot}5$ inches the thickness of the vertical plates between $(A_{,}B_{,})$ and $(a_{,}b_{,})$, including the sides opposite to them.

Now if f be the force exerted by the particles in a unit of section, and at a unit of distance from the neutral line, as before, we have—taking that unit as one inch—

$fa = f \times 138{\cdot}16$, the force of the particles in a unit of section at the top of (AB);

$f\left(a - \frac{t}{2}\right) = f \times 137{\cdot}785$ „ „ „ „ centre of (AB);

$f(a - t) = f \times 137{\cdot}41$ „ „ „ „ bottom of (AB), to which the angle irons are attached;

$f((Na) + t) = f \times 116{\cdot}41$, the force of the particles in a unit of section at the top of (ab), to which the angle irons are attached;

$f\left((Na) + \frac{t}{2}\right) = f \times 116{\cdot}035$, the force of the particles in a unit of section at the centre of (ab);

$f \times (Na) = f \times 115{\cdot}66$ the force of the particles in a unit of section at the bottom of (ab).

In like manner—

$f \times 166{\cdot}215 =$ force of the particles in a unit of section at the bottom of $(A_{,}B_{,})$;

$f \times 165{\cdot}715 =$ „ „ „ centre of $(A_{,}B_{,})$;

$f \times 165{\cdot}215 =$ „ „ „ top of $(A_{,}B_{,})$, to which the angle irons are attached;

$f \times 143{\cdot}215 =$ force of the particles in a unit of section at the top of $(a_{,}b_{,})$;

$f \times 143{\cdot}715 =$ „ „ „ centre of $(a_{,}b_{,})$;

$f \times 144{\cdot}215 =$ force of the particles in a unit of section at the bottom of $(a, b,)$, to which the angle irons are attached.

We will first obtain the moments of the forces of the plates, and afterwards those of the angle irons.

Moments of the Forces of the Plates.

To determine these, the same mode will be adopted as in Problem 3, giving the computation without full explanation, which may be found in that Problem.

1st. To obtain the moments of the forces of the plates composing the sides $(a a,)$ and $(b b,)$, neglecting those of the cells. If we consider the sides (Na), (Ob), and $(Na,)$, $(Ob,)$, above and below the neutral line, as acting like rectangular masses, or joists bent transversely, the moments of their resistance, determined as in page 71, will be as below:—

$$\frac{f \times 115{\cdot}66}{3} \times s\,(Na)^3 = \frac{sf \times 115{\cdot}66}{3} \times (115{\cdot}66)^3 = sf \times \frac{(115{\cdot}66)^4}{3} =$$

the moments of the former.

$$\frac{f \times 143{\cdot}215}{3} \times s \times (Na,)^3 = \frac{sf \times 143{\cdot}215}{3} \times (143{\cdot}215)^3 = sf \times \frac{(143{\cdot}215)^4}{3} =$$ the moments of the latter.

$$\therefore \text{their sum} = sf\left(\frac{(115{\cdot}66^4 + (143{\cdot}215)^4}{3}\right) = sf\left(\frac{1547211 + 2937416}{3}\right)$$

$= 1494875f$ (s being $= 1$) . . . . . (*A*).

2nd. To obtain the moment of the forces of the vertical plates in the top and bottom cells of the tube.

For the moments of the forces in the top cells, estimating as above; first, the moment of the resistance of the vertical plates, on the supposition that these plates extend down to the neutral line, and then deducting from that result the estimated movements of resistance of the particles which had been assumed to extend from the top cells to the neutral line; we shall have, for the moments from the vertical plates between (AB) and $(a b)$, $\frac{f(a-t)s'}{3}(a-t)^3 = \frac{fs'}{3}(a-t)^3 = \frac{f \times 6{\cdot}75}{3} \times (137{\cdot}41)^3$, the moment of the forces, supposing the vertical plates to extend from the bottom of (AB) to the neutral line. $\frac{f((Na)+t)s'}{3}((Na)+t)^3 = \frac{fs'}{3}((Na)+t)^3 = \frac{f \times 6{\cdot}75}{3} \times (116{\cdot}41)^3$ the moments of the forces from the top of $(a b)$ to the neutral line.

Taking the latter of these moments from the former, gives, for the

moment from the vertical plates in the top, or compressed part of the tube, $\frac{f \times 6{\cdot}75}{3}((137{\cdot}41)^3) - (116{\cdot}41)^3 = 2288256f$ . . . . . (1).

In like manner the moments of the vertical plates in the bottom cells of the tubes will be,

$\frac{f(a_1 - t_1)s_1}{3}(a_1 - t_1)^2 = \frac{fs_1}{3}(a_1 - t_1)^3 = \frac{f \times 3{\cdot}5}{3}(165{\cdot}215)^3 =$ those from the top of (A, B_1) to the neutral line.

$\frac{f((Na_1) + t_1)s_1}{3}((Na_1) + t_1)^2 = \frac{fs_1}{3}((Na_1) + t_1)^3 = \frac{f \times 3{\cdot}5}{3} \times (144{\cdot}215)^3$ = those from the bottom of (a, b_1) to the neutral line.

Taking the latter moment from the former gives $\frac{f \times 3{\cdot}5}{3}$ $((165{\cdot}215)^3$ $-(144{\cdot}215)^3) = \frac{f \times 3{\cdot}5}{3}(4509708 - 2999378) = 1762052f$ . . (2), the moments of the forces of the plates in the bottom cells of the tube.

Adding together the moments in (1) and (2) gives,

$$2288256f + 1762052f = 4050308f \quad . \ . \ . \ . \ (B),$$

the moments from the vertical plates in the cells.

3rd. To obtain the moments of the forces of the horizontal plates (AB), (ab), (A, B_1), and (a, b_1), with those of the additional plates attached to them.

The moment from each of these is equal to the product of the three following values—the strain upon a square inch of the plate—the area of its section—and the distance of its centre from the neutral line.

Hence, for the moment of the plates in (AB), the distance of the centre of gravity of which from the neutral line is $\left(a - \frac{t}{2}\right)$, we have,

$$f\left(a - \frac{t}{2}\right)bt \times \left(a - \frac{t}{2}\right) = fbt\left(a - \frac{t}{2}\right)^2$$

$$= f \times 169{\cdot} \times {\cdot}75 \times (137{\cdot}785)^2 = 2406311f \quad . \ . \ . \ . \ . \ (1).$$

For those in (ab), the distance of its centre from the neutral line being $(Na) + \frac{t}{2}$, or 116·035, we have,

$$f\left((Na) + \frac{t}{2}\right)bt \times \left((Na) + \frac{t}{2}\right) = fbt\left((Na) + \frac{t}{2}\right)^2$$

$= fbt(116{\cdot}035^2 = f \times 169 \times {\cdot}75(116{\cdot}035)^2 = 1706577f$ . . . (2).

To the top of (AB), the distance of which from (NO) is a, there are 9 plates attached, the area of the section of which is

$$9 \times 9 \times \frac{1}{2} = 40{\cdot}5 \text{ square inches.}$$

The moment of their forces is therefore

$$fa \times 40{\cdot}5 \times a = f \times 40{\cdot}5\,(138{\cdot}16)^2 = 773071f \quad . \quad . \quad . \quad . \quad (3).$$

To the bottom of (ab), there are likewise attached 7 plates, with an area of section $= 7 \times 9 \times {\cdot}5 = 31{\cdot}5$ square inches.

The moment from these is,

$$f \times (Na) \times 31{\cdot}5 \times (Na) = f \times 31{\cdot}5\,(Na)^2$$
$$= f \times 31{\cdot}5\,(115{\cdot}66)^2 = 421383f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

The moment of the forces of tension in $(A,B,)$ is, in like manner,

$$f \times 165{\cdot}715 \times bt, \times 165{\cdot}715 = fbt,(165{\cdot}715)^2$$
$$= f \times 169 \times 1 \times (165{\cdot}715)^2 = 4640987f \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

And those in $(a,b,)$,

$$f \times 143{\cdot}715 \times bt, \times 143{\cdot}715 = fbt,(143{\cdot}715)^2$$
$$= f \times 169 \times 1 \times (143{\cdot}715)^2 = 3490526f \quad . \quad . \quad . \quad . \quad . \quad . \quad (6).$$

Adding together the values in (1), (2), (3), (4), (5) and (6), gives the moment of the forces from the horizontal plates, $2406311f + 1706577f + 773071f + 421383f + 4640987f + 3490526f = 13{,}438{,}855f$. (C).

The sum of the moments in (A), (B) and (C), or $1494875f + 4050308f + 13438855f = 18{,}984{,}038f =$ those of the forces from all the plates in the tube . . . . . (D).

Moments of the Forces from the Angle Irons.

Of these there are 40 in the corners of the top cells, and 32 in those of the bottom ones of the tube. The angle irons in the top cells have each an area of 4 square inches in their section; and those in the lower cells of $2\frac{1}{2}$ square inches. There are 18 angle irons attached to the lower side of the plate (AB), at a distance $a - t = 137{\cdot}41$ inches from the neutral line. There are, likewise, 22 angle irons attached to the plate (ab); 18 of these are attached to its upper side, at a distance $(Na) + t = 116{\cdot}41$ inches from the neutral line; and the other 4, at the bottom of (ab), 115·66 inches from the neutral line. There are 14 angle irons attached to the top of the bottom plate $(A,B,)$, at a distance of 165·215 inches from the neutral line; 14 attached to the bottom of $(a,b,)$, at a distance of 144·215 inches; and 4 to its top, 143·215 inches from the neutral line.

Moments of angle irons attached to (AB),

$$f(a - t) \times 18 \times 4\,(a - t) = f \times 72\,(a - t)^2$$
$$= f \times 72\,(137{\cdot}41)^2 = 1359468f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

Moments of those attached to top of (ab),

$$f((Na) + t) \times 18 \times 4\,((Na) + t) = f \times 72\,((Na) + t)^2$$
$$= f \times 72\,(116{\cdot}41)^2 = 975692f \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

Moments of those attached to bottom of (a,b),

$$f \times 115{\cdot}66 \times 4 \times 4 \times 115{\cdot}66 = f \times 16\,(115{\cdot}66)^2 = 214035f \quad . \quad . \quad (3).$$

Moments of angle irons at the top of (A,B),

$$f \times 165{\cdot}215 \times 14 \times 2{\cdot}5 \times 165{\cdot}215 = f \times 35\,(165{\cdot}215)^2 = 955359f \quad . \quad (4).$$

Moments of those at the bottom of (a,b),

$$f \times 144{\cdot}215 \times 14 \times 2{\cdot}5 \times 144{\cdot}215 = f \times 35\,(144{\cdot}215)^2 = 727928f \quad . \quad (5).$$

Moments of those at the top of (a,b),

$$f \times 143{\cdot}215 \times 4 \times 2{\cdot}5 \times 143{\cdot}215 = f \times 10\,(143{\cdot}215)^2 = 205105f \quad . \quad (6).$$

Adding together the results in (1), (2), and (3), we have

$$1359468f + 975692f + 214035f = 2{,}549{,}195f \quad . \quad . \quad . \quad (E),$$

the moments of the forces from the compressed angle irons.

The sum of the results in (4), (5), and (6), gives,

$$955359f + 727928f + 205105f = 1{,}888{,}392f \quad . \quad . \quad . \quad . \quad (F),$$

the moments of the forces of the extended angle irons, supposing them to act with their full tensile force.

The whole resisting forces in the tube arise from the plates and the angle irons. Taking the several moments from these, as in (D), (E), and (F), we have,

Moment from plates	18,984,038f	
„ compressed angle irons .	2,549,195f	
„ extended „ .	1,888,392f	
Sum of the moments . .	23,421,625f . . .	(G).

It is probable that the extended angle irons may, from imperfect joining at the ends, not act with their whole tensile strength; hence, taking the moment from them at one-half of what it is computed, or $944196f$, gives for the whole moment $22{,}477{,}429f$ . . . . . (H).

It is here supposed that the position of the neutral line is not sensibly changed by these different suppositions with respect to the action of the angle irons.

To compute the Strength from the preceding Moments.

If we consider, as before, the tube to be supported at the ends, and loaded in the middle, each end will have to sustain half the weight, and its distance from the middle will be half the span.

Hence, if w be the weight in the middle of the tube, l the span, or distance between the supports, and G, or H, the moments in (G) or (H), we have

$$\frac{w}{2} \times \frac{l}{2} = G \text{ or } H.$$

Putting mf = the moments of the forces in (G), or (H), we have

$$w = \frac{4mf}{l}.$$

The strength depends upon f, which, as defined in page 85, is a quantity such that $a \times f$ = the force per square inch, with which the tube is compressed at the top; or $a, \times f$, the force with which it is extended at the bottom.

If we suppose it, as before, to be compressed at the top, to the extent of 8 tons per square inch, then $a \times f = 8$; and since a, the distance of the top from the neutral line, is 138·16 inches,

$$\therefore f = \frac{8}{138{\cdot}16} = {\cdot}0579 \text{ ton.}$$

Substituting this for f, in the formula above, gives

$$w = \frac{4mf}{l} = \frac{4m \times {\cdot}0579}{l} = \frac{{\cdot}2316 \times m}{l} \text{ tons,}$$

the weight which a tube, of the lateral dimensions of that at Conway, would support, when it was compressed at the top, to the extent of 8 tons per square inch, which, I conceive, is the greatest strain to which it should be subjected.

The distance between the supports, on which the Conway Tube will be laid, is 400 feet = 4800 inches, and taking the values of m, from those in (G) and (H),

$$\text{we have } w = \frac{{\cdot}2316 \times 23421626}{4800} = 1130{\cdot}09 \text{ tons,}$$

when the angle irons are considered to act with the full force due to the material.

$$\text{Or, } w = \frac{{\cdot}2316 \times 22477429}{4800} = 1084{\cdot}5 \text{ tons,}$$

when the bottom angle irons are only considered as acting with half their tensile force.

Taking the lower estimate of the strength, it appears that 1084·5 tons, laid on the middle of the tube, the pressure from its own weight being included, would cause the plates of the upper cells to be compressed, in the direction of their lengths, to the extent of 8 tons per square inch; and, since the distances of the top and bottom of the tube, from the neutral line, are 138·16 inches, and 166·215 inches respectively, the simultaneous strain in the plates, at the bottom of the tube, would be $\frac{166{\cdot}215}{138{\cdot}16} \times 8 = 9{\cdot}6$ tons.

Supposing the elasticity to remain uninjured, and the top plates of the tube to be compressed, in the direction of their lengths, to the extent

of 12 tons per square inch, or half as much again as in the former case, the extension per square inch, at the bottom would be $\frac{3}{2} \times 9{\cdot}6 = 14{\cdot}4$ tons, and the weight which the tube would be supporting, including that from its own mass, would be $\frac{3 \times 1084{\cdot}5}{2} = 1626{\cdot}7$ tons.

In my former Report on the Conway Tube, as then proposed, I showed from the results of several experiments, that wrought iron, strained by *tension* beyond about 15 tons per square inch, or by *compression* beyond 12 tons, would be destroyed for all practical purposes. It was likewise shown, that a weight of 12 tons per square inch produced a decrement of about $\frac{1}{863}$rd of the length.

It would appear from the preceding computation and remarks, that a tube of these dimensions, if made without joints and loaded without vibration, would bear a weight in the middle, including the pressure from its own weight, of 1627 tons, without entirely destroying the utility of the material. But plates united by riveting in the best manner, in common use, are weaker than plates without joints, in the ratio of 3 to 2 nearly; we ought, therefore, to reduce the computed breaking weight, in that ratio, or even a greater, since the computation is made on the supposition of the tube being without joints, and loaded without vibration.

Radius of Curvature of the Conway Tube.

It has been mentioned before, and was shown in the preceding Report, that wrought iron, compressed with a force of 12 tons per square inch, will be reduced in length about $\frac{1}{863}$rd; and that the radius of curvature of the tube, when its top is compressed to this extent, will be equal to $863a$, where a is the distance of the top from the neutral line. In the proposed tube this distance is 138·16 inches (see page 84), and taking 12 tons per square inch as the greatest weight the tube will bear, without destroying the utility of the material by compression, its radius of curvature will then be $138{\cdot}16 \times 863 = 9936$ feet $= 1{\cdot}88$ mile.

Deflexion of the Tube.

As this tube was not intended to be uniform throughout, but somewhat less in depth towards the ends than in the middle, its deflexion was not then computed, especially as it was not expected to differ much from that of the former tube.

Supposing it to be uniform throughout, we should have (from page 80), $\delta = \frac{wl^2}{6mE}$, the values of which, applied in the present tube, give

$$\delta = \frac{(2400)^2 \times w}{6 \times 22477429 \times 10714{\cdot}3} = {\cdot}00956691\, w;$$

where δ is the deflexion, and w the weight in the middle of the tube.

If $w = 1626{\cdot}7$ tons, the weight which would compress the tube to 12 tons per square inch at the top (see last page),

$$\delta = {\cdot}00956691 \times 1626{\cdot}7 = 15{\cdot}56 \text{ inches},$$

the utmost deflexion it might be expected to bear with safety.

The tube, if bent by its own weight, would be deflected $\frac{4}{8}$ths of what it would have been, if the same weight had been suspended from the middle.

The weight was stated to be 1300 tons nearly; the deflexion from the weight alone might, therefore, be expected to be

$$\delta = {\cdot}00956691 \times \tfrac{5}{8} \times 1300 = 7{\cdot}773 \text{ inches}.$$

Riveting of the Tubes.

As the transverse strength of tubes depends principally upon their power to resist puckering at the top, and tearing asunder the riveted parts at the bottom, and as the former can generally be avoided by increasing the thickness of the plates at the top, it was very necessary that the riveting should be good. My former experiments had shown that a double row of rivets, alternating with each other, increased considerably the strength over that obtained from one row. To unite the large plates at the bottom of the tubes, the ends having been brought together, two small plates or bands of iron, the united thickness of which was somewhat greater than that of each plate, were used. These small plates or bands were laid over and under the joint of the large plates to be united; and each large plate was united to the bands, and thus to each other, by two rows of riveting, four in all. In cases where the strength was wished to be as near to that of the plates to be united as possible, three rows of rivets instead of two, six in all, placed alternately, were employed to form the joint. The union of the plates in the top of the tube was often effected by employing one strong plate, instead of two, as the joint in this case had to resist a thrust, and needed only to have the plates kept in a straight line, and pressing throughout against each other.

Our extracts from the Parliamentary Report cease here, for, to our great regret, the scope of this supplement will not allow us to incorporate in it the whole of the Tables of Experiments so skilfully, so carefully carried out by Mr. Hodgkinson. In the text we have introduced references to them, precisely as they occur in the original

document, so that the reader may be facilitated in the consultation of the Report, should he require more definite, or more detailed information with respect to them. For all practical purposes, however, we have thought that the abstracts embodied in the portions of the text we have availed ourselves of contain as much as is usually required.

Indeed, from the fact that Professor Willis has undertaken to revise the whole question of the resistance of materials, the necessity for our endeavouring to combine such highly important subjects with our own practical observations upon the different materials employed in the construction of bridges, has been entirely obviated. The elaborate character of the investigations connected with the resistance of materials demands, moreover, so vast an amount of knowledge of the higher branches of the mathematics, that it must be a matter of congratulation to the whole body of the profession, that so eminent an authority as Professor Willis should have undertaken to execute them. We have, therefore, stopped our extracts at the close of the interesting Appendix furnished by Mr. Hodgkinson, leaving the results obtained from the experiments upon passing weights, and frequently repeated percussion, to be treated by the abler hands of the Professor.

In this number of our Supplement, we have inserted the computations made by Mr. Hodgkinson, to ascertain the strength of the respective designs made for the Conway and Menai Bridges. We would call particular attention to them, as illustrating the character of the calculations necessary to be made before commencing any large or unusual kind of construction. Had such careful and elaborate investigations been made more frequently during the execution of the immense public works lately erected in England, in all probability many of the failures which have occurred might have been avoided. At any rate, we find in this case, that in consequence of the wonderful skill, the patient investigation, and the sound judgment of all the parties connected with these works, not only has success crowned the first attempt to execute bridges of the astounding character of those in question, but that even at present, with all the advantages of experience, very little change can be suggested in the details—none in the important principles of the construction. Where all parties concerned have so nobly concurred to attain such eminently successful results, it is almost impossible to award praise to any one in particular. Yet, if we might be allowed to make any distinction, after firstly expressing our admiration of the originality of conception on the part of Mr. Stephenson, we would dwell with the most satisfaction upon the scientific ability displayed by Mr. Hodgkinson.

DESCRIPTION OF ILLUSTRATIONS.

Nos. XI., XII., XIII., XIV., AND XV. PLAN, ELEVATION, AND DETAILS OF THE BRIDGE OVER THE COMMERCIAL ROAD, FOR THE BLACKWALL EXTENSION RAILWAY.

THIS very beautiful application of wrought-iron to the purposes of bridge building, was executed by Messrs. Fox and Henderson, under the directions of Joseph Locke, Esq., M.P., Engineer for that line of railway.

For moderate spans, such in fact as occur most frequently in the practice of engineers in our country, the principle adopted in this bridge is unexceptionably the most reasonable. To lighten the beam in the parts where material only acts injuriously by its weight, is so evidently the logical course to be followed, that we may almost wonder at the choice of any other principle, unless very cogent reasons of economy should influence the decision of the material to be adopted. If the foundations upon which such bridges have to be erected be exposed to danger from a superincumbent weight, the preference to be accorded to such light structures is self-evident; and if the extra labour in constructing the bow-string girders, as Messrs. Fox and Henderson call the ones we are now considering, be not a source of greater expense than the introduction of the solid sides used in the ordinary plate-iron bridges, we may fairly express our astonishment at the prevalence of the latter very ugly, and comparatively speaking somewhat unphilosophical, structures now being erected in such numbers throughout the length and breadth of the land.

The form of the bow-string bridge admits of its attaining the nearest practical approach to that of a solid of greatest resistance; and at the same time that the useless material about the neutral axis is economized, all that is above the line formed by the figure of the solid of greatest resistance is dispensed with. Such a bridge must, therefore, with less material, present greater strength than one executed with straight plate-iron girders, besides possessing the advantage of loading the foundations to a considerably smaller extent.

But the example before us seems open to some criticisms, or rather, as occurs with all new inventions, practical experience has discovered certain defects which were not suspected in the commencement, or has led to the suggestion of improvements in the details. Thus, it is more than questionable whether it would not be preferable to have substituted cast iron for wrought, in the construction of the bow. The effort this bow has to resist is entirely one of compression, and the relative superiority of cast iron in such a position is far too well known to require us to dwell upon it here. A certain difficulty would arise in the execution, from the great length of castings required; but that might be obviated either by making them upon the system of M. Polonceau, or upon that introduced by our ingenious countryman Mr. Charles de Bergue. At any rate, the difficulty is a mere mechanical one, and not of a nature to inspire much anxiety. Perhaps, also, the form of the links of the bow-string may be open to some objection. In

fact, Mr. Fox has himself lately made a series of experiments, which led him to believe that we have not yet arrived at the true form to be given to the links of a chain exposed to an effort of traction.

The manner in which the St. Andrew's crosses are brought together and tightened up, is also defective, insomuch that if the whole work be not executed and put together with mathematical precision, an unequal settlement may occur. We find, indeed, that after the proofs, a permanent movement had taken place; that is to say, that the girder did not resume its perfect horizontality. This was evidently owing to the fact that the works were taking their bearings, to use a workman's phrase. Doubtlessly no danger existed, nor was there any reason to dwell upon the appearance thus presented, for it could at once have been obviated by keeping the bottom line of the girder enough above the horizontal line to compensate for this trifling deflection. But since unequal strains are sometimes produced when works are thus left to find their own bearings, it is preferable to avoid such actions, if possible. We propose to give hereafter an illustration of a system of bow-string bridge, in which this inconvenience is attempted to be obviated.

The manner in which the transverse bearers are attached to the main girders is also open to objection. As they were executed on this bridge they produce an effort of torsion on one side only of the girders; nor are they so solidly fixed as they would have been, supposing them to have borne alike upon the external as upon the internal faces.

In the proofs of the two girders forming the main part of the structure of this bridge, the load was laid upon 16 intermediate points in the length, and consisted of a series of weights equal to 18 tons, applied at each point, or 288 tons in all, upon each beam. The effects produced were as follows, the falls being measured at the respective points where the weights were applied:—

GIRDER No. 1.

	2 and 3 loaded.	2, 3, 4 and 5 loaded.	2 to 9 inclusive.	2 to 11 inclusive.	All loaded.
	Inch.	Inch.	Inch.	Inch.	Inch.
Fall at No. 1.	0·01	0·04	0·04	0·05	0·05
2.	0·025	0·075	0·1	0·12	0·15
3.	0·025	0·105	0·16	0·2	0·23
4.	0·03	0·1	0·2	0·25	0·3
5.	0·025	0·075	0·23	0·28	0·34
6.	0·025	0·075	0·24	0·31	0·38
7.	0·015	0·075	0·235	0·31	0·39
8.	0·015	0·07	0·23	0·305	0·4
9.	0·015	0·06	0·21	0·295	0·395
10.	0·015	0·055	0·195	0·285	0·38
11.	0·015	0·05	0·18	0·255	0·365
12.	0·015	0·04	0·15	0·225	0·335
13.	0·015	0·02	0·11	0·17	0·28
14.	...	0·015	0·075	0·14	0·23
15.	...	0·005	0·035	0·075	0·14
16.	...	0·005	0·015	0·025	0·053

The load was applied on the 3rd of June, 1848, and left on till the 6th. The deflection was taken on the 5th and 6th, and found to be precisely the same as upon the 3rd. The moveable shoe was affected by the diurnal changes of temperature; but it was found to occupy the same position upon the 6th that it had occupied on the 3rd.

PROOF OF GIRDER No. 2.

	Load on Points 2 to 9 inclusive.	Load on all Points.	Load removed.
Fall at point No. 1.	0·218	0·307	0·239
2.	0·302	0·458	...
3.	0·380	0·552	0·322
4.	0·427	0·658	0·354
5.	0·458	0·708	0·385
6.	0·458	0·760	0·395
7.	0·458	0·796	0·395
8.	0·442	0·822	0·416
9.	0·421	0·822	0·421
10.	0·385	0·812	0·427
11.	0·343	0·791	0·427
12.	0·322	0·770	0·427
13.	0·276	0·708	0·416
14.	0·229	0·645	0·406
15.	0·198	0·552	...
16.	0·125	0·411	...

It may fairly be asked why, even supposing wrought iron be the material chosen for the bows, the form should be made square, instead of circular, in section. Certainly there is an economy in the workmanship of a square tube over that of a circular one. But as Mr. Hodgkinson's experiments in this case confirm the previous deductions from theory, that the most judicious arrangement of a definite quantity of material to resist a strain, either of compression or extension (the thickness being of course varied in the upper or lower portions, according to the nature of the material employed), is to make it assume the form of a circle, there hardly seems any determining reason why that should not have been adopted. No observations appear to have been made during the trials upon the changes of form assumed by the bow.

The objections we have ventured to make may be considered hypercritical; but such really meritorious constructions as the ones we are considering can best afford to support them. The questions we raise merely regard details; the main principles which distinguish this invention from the many other applications of wrought iron, are quite removed from the discussion. Whatever opinion we may arrive at upon the points mooted, we must agree that the bow-string bridges are the most logical, and the most economical applications of the material so much in fashion just now, which we can meet with. Upon the Blackwall Railway, the two bridges erected upon this principle, one over the Regent's Canal, and the other over the Commercial Road, are, in fact, the only works which merit a special examination, although the whole line has been

executed in the face of every kind of difficulty with the most utter recklessness of cost or possible return to the unfortunate shareholders. As a recent Reviewer observed, such a line must ever remain an inexplicable phenomenon.

Nos. XVI., XVII., AND XVIII. BRIDGE OVER THE THAMES AT RICHMOND, ON THE RICHMOND RAILWAY. J. LOCKE, ESQ., M.P., ENGINEER.

Few of our modern engineers have been so successful as Mr. Locke in the economical application of cast iron. Upon the Grand Junction, and upon some of the Scotch railways, are numerous instances of the great skill with which he has applied that material. The Richmond Railway, with its loop lines, comprises some works of a similar character, including three bridges over the Thames, from which we have chosen the example before us to illustrate the actual state of professional practice in similar cases.

At the present day there are no questions as to the scientific construction of such bridges to be solved; for the researches of Tredgold, Barlow, and Hodgkinson have settled every one which might arise as to the form and disposition of the mass of the material. In the instance before us, however, it may admit of discussion, more on the score of taste than on any other, whether the arrangement of the spandril filling might not have been modified. When a load is brought to bear upon the extrados of an arch, there is always the appearance of a false bearing, unless the lines of its direction be normal to the arch itself. In a cast-iron bridge this remark does not apply with the same force that it would if any other material had been employed; but we are so much the creatures of habit, that our preconceived notions of solidity are certainly more gratified if we find the same principles of construction followed in all cases. It is for this reason that the spandril fillings of the Southwark and of the Lara Bridges, produce so much more agreeable effects upon the eye than the filling Mr. Locke usually adopts.

With this exception, and it is hazarded more as a question of taste than as being of any constructive importance, the bridges on the Richmond and Windsor line are elegantly proportioned, and very economically constructed. The foundations of one of them yielded, and to a certain extent injured the appearance of the masonry. But it was one of the first essays on a large scale of a new system of constructing the foundations of bridges; and, as always occurs in such cases, practical difficulties arose which involved movements of the superstructure, deforming it a little, although they in no wise compromised its solidity after the necessary repairs had been effected. The Barnes and the Richmond Bridges were founded in the usual manner, by means of coffer-dams, from which the water was pumped out, and the masonry laid dry. In the execution of the Windsor Bridge, Dr. Pott's system of cylinder piles was adopted; but from the cylinders not having been driven sufficiently deep into the ground, or from the existence of a compressible bed beneath them, the piers sank unequally. The defects were remedied very successfully; nor has any subsequent danger manifested itself. The slight failure also must not be considered to prejudice in any way the merits of Dr. Pott's system. It was, in fact, merely one of the class of mishaps which so often attend the introduction of even the most useful or perfect inventions.

The coffer-dams of the Barnes Bridge were thrown out to a depth of 28 feet from high-water mark; the thickness of the puddle being made 4 feet 6 inches. According to Belidor's rule, which, by the way, is evidently in excess of the real strength required, the dimensions of these coffer-dams were far too feeble. Belidor would have required the thickness to have been about 15 feet over all, for he states that, up to 9 feet, the thickness of a dam should be made equal to its height, and that beyond 9 feet in depth, 1 foot should be added to the thickness for every 3 feet in height. Rondelet recommends that, up to 9 feet in depth, two-thirds of the perpendicular dimension be taken for the thickness, and that the subsequent augmentation be according to Belidor's rule; namely, 1 foot in thickness for every 3 feet in height. Even this would have required the dams of 28 feet depth to have been 12 feet wide, which is still far in excess of modern practice in such works; but at any rate the results proved that the thickness given to the dams for the Barnes and Richmond Bridges was far too little; they certainly should not have been less than 7½ feet thick, even with the most perfect system of cross-strutting possible. It is perhaps one of the evils attendant upon the railway system, that the extreme rapidity and economy of construction they require, induce engineers to encounter risks for the attainment of these objects. Perhaps also professional men are, under such circumstances, induced to leave too much to the practical skill of their contractors, as Mr. Hughes stated in the previous part of this work. In the case under our consideration, for instance, it is almost doubtful whether the dimensions of the coffer-dam were prescribed in the specification for the execution of the bridge. Belidor and Rondelet's rules lead evidently to an excess of strength; but the coffer-dams used on this line were nearly as much in error in the opposite direction; they were only maintained by constant works of consolidation, and at all times inspired great fears for their powers of resistance. The reader who may desire more detailed information upon the subject of apportioning the strength of coffer-dams, is referred to an able paper contributed by J. Neville, Esq., to the "Civil Engineer and Architect's Journal of 1840," page 78, and subsequently.

In some cases it was found to be impossible to keep out the water; and when this took place the concrete was conveyed to the bottom by means of a water-tight tube, so as to prevent the stream from washing away the uncombined lime. Similar cases often arise in practice, and much difference of opinion exists as to the best manner of executing concrete when they do so occur. But the essential principles to be observed unquestionably are, that the lime be properly reduced to the state of a hydrate before being mixed with the ballast or shingle; and, secondly, that the concreting mass be removed from the action of running water as much as possible. The Editor has seen, in some very important hydraulic works executed near London, the unslacked lime mixed with the ballast, and the whole thrown in loosely from above, without the intermission of any shoot, or other similar contrivance. Unfortunately, although such a proceeding is absurd, unphilosophical, and ridiculous to the highest degree, it is so common that it is almost necessary to call attention to it. The whole of the practice of English engineers, especially of those in London, is, however, very defective in all that regards the use of lime; and it were very desirable that their

attention were more particularly directed to the qualities and mode of action of this common but all-important material. The system adopted in executing the foundations of the bridges upon this line, when it became necessary to execute the concrete under water, merits therefore particular notice.

Perhaps it would have been more advisable to have made the springing-plates of the arches continuous throughout the whole length of the piers, instead of merely making them long enough to receive the girders in immediate contiguity to one another. Such a continuous springing-plate would have divided the insistent weight over a larger surface of the pier, and would certainly have bound together in a more perfect manner the upper structure. The saving of metal must have been so small, that it is to be regretted that a consideration of economy should have been allowed to interfere.

The form given to the meeting-joint also admits of criticism, because although, when the meeting flanges of the girders are bolted together, the separate portions cannot act freely as voussoirs, yet it would have been desirable to have kept the line of the joint normal to the curve throughout its length; at any rate, it would have been more easy to have made the joint true, if it had been in an unbroken line, than in the complicated form it actually presents.

The Barnes Bridge differs from that of Richmond in this, that the arches are of 120 feet span by 12 feet versed sine. The arch of the inner girders was 3 feet deep in all, and consisted of a bottom flange 10 in. wide by 3 in. thick; an upright web 2 in. thick, and a top flange 8 in. wide by 2 in. thick, in which a groove was made to receive the spandril filling. With the exception of the increase of strength necessary on account of the greater span, there is no essential difference in these bridges. The elevation of the Barnes Bridge is rather more ornamental than that of Richmond.

The mode of carrying the roadway upon joists and planking is certainly economical in the first construction; but, unless there were very cogent reasons for economy, it would have been preferable to execute this part of the structure in a more definite and permanent manner. It often happens, however, that mere local considerations interfere with the attainment of what we may style theoretical perfection in these details.

Note upon Dr. Pott's Patent Pneumatic Apparatus for Sinking Foundations by means of Atmospheric Pressure in Deep Water, Moveable Sands, Mud, Shingle, or Bog, especially with Reference to the Windsor Bridge, and upon Pile Foundations in general.

This invention, which is the subject of a patent, is for improvements in the construction of foundations (under any of the circumstances mentioned above) for piers, embankments, breakwaters, or other similar constructions. It is equally applicable for the sinking of wells in analogous positions.

It consists in the use of hollow tubes, usually of cast iron, of any size, and almost of any shape, which are sunk into their places by means of the atmospheric pressure. The lower extremity of the tube is open, and being placed upon the ground, of whatever nature it may be, the air, water, or semi-fluid

material in the inside is extracted by pumps, or by any of the usually employed methods. When the more solid materials are removed, it is usual to create a vacuum, or, more correctly speaking, to rarefy the air in the interior of the tubes, by placing them in communication with large vessels, from which the air is previously withdrawn by means of a pipe and a stop-cock. As soon as the communication is effected, the air in the interior of the tubes rushes into the empty vessels, leaving the atmospheric pressure upon the pile-head without any counteracting resistance. If the strata to be traversed be of a yielding semi-fluid nature, they are also acted upon by the same cause, and flow up into the tube, or hollow pile, which at the same time descends with corresponding rapidity. The materials thus introduced are removed, or, if the strata be more resisting, they are thrown out, so as to attain the greatest possible rarefaction of the air, and the operation is repeated until the piles are fully driven. A succession of tubes may be placed upon the first by means of flanges, or other joints, so that they may be driven of any length required.

The shapes of the tubes usually employed are either cylindrical, angular, or conical; they may be made to fit into one another so as to form a continuous close piling; or they may be made with grooves to receive plates, such as have been employed upon the river-walls of the Thames.

Upon the first introduction of this invention, it was applied more as a means of driving hollow piles of the usual dimensions of wooden ones. Subsequent experience has led to a considerable modification in its use. The fact that the atmospheric pressure is in the proportion of the surface exposed to its action has induced the patentees to increase the diameter of the piles gradually, until at length they have ceased to act in a manner such as we are accustomed to consider the latter to act. We shall revert to this subject in noticing some practical applications of the principle.

The principal advantage Dr. Pott's system possesses over every other manner of pile-driving, consists in the fact that no vibration is communicated to the ground, and that the elasticity of the strata traversed is never brought into action. A remarkable illustration of its advantages in this respect occurred on the Goodwin Sands, where a tube 2 feet 6½ inches in diameter sunk to a depth of 32 feet 7 inches in six effective working hours; whereas a bar of iron 3 inches in diameter could not be driven more than 13 feet, at which depth it required 46 blows of a monkey weighing 10 cwt., falling through 10 feet, to advance it one inch. In such sandy soils, and sometimes also in clay soils, it is necessary to drive common piles with the large, or butt-end downwards, to prevent the elasticity from positively forcing them up again.

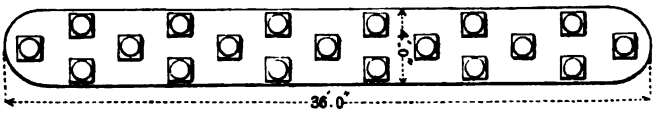
Notwithstanding all that has been said upon the subject of foundations, there still appears to be a considerable amount of uncertainty in the practical application of our knowledge to the execution of such works, and it may perhaps be advisable in this supplement, which is intended principally to treat of practical questions, to dwell at length upon one of such vital importance to the solidity of any engineering construction. It often happens, indeed, that an untoward circumstance like the one which occurred on the Windsor Bridge, is a more fruitful source of instruction than even a decided success. Let us try to derive as much benefit as possible from the present occasion.

In all cases where foundations are to be based upon strata which in their natural state would be unquestionably fit to receive any superstructure, it is necessary to examine whether they be liable to decomposition by being placed in contact with the air or the water. The universally received opinion of engineers and architects in England appears to be, that the London clay is of a perfectly homogeneous character throughout its whole thickness, and that as soon as a foundation has been carried down to it, all fears of its solidity are at once to be banished. Like all general rules, this appears to be only admissible with a reservation. Especially upon the outcrop of the subjacent strata, we are exposed to meet with beds of a much less resisting character beneath it; and it also sometimes happens, that, if water be introduced within the clay itself, as arises when the piles are driven immediately into it, the water forcing its way by the side of the piles, the clay becomes softened. In making the soundings for any heavy structure, through the strata of the London Basin, it is therefore necessary to continue them to a considerable depth below the surface of the blue clay, to ascertain whether there be a sufficient thickness of that formation between the intended bottom level of the foundations and the more yielding strata intercalated between it and the great bed of the plastic clay formations.

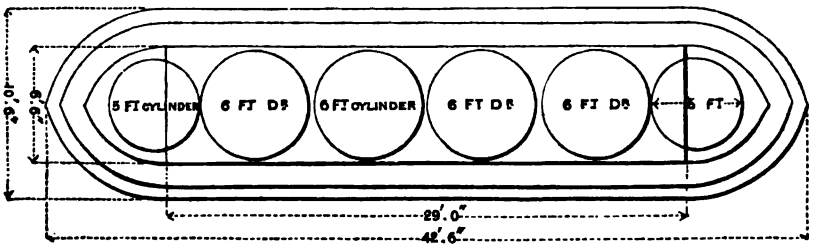
In the Windsor Bridge the cylinder piles were driven through a stratum of gravel, into which they penetrated with difficulty, and were carried down into the London clay. It was necessary to hurry on the work, and the precaution of loading the foundations before carrying up the remaining portions of the bridge could not be taken. One of the piers sank bodily, after it had remained in its position a considerable time, but the movement was greatest towards one end of the pier. Now the probability is, that in this precise position the London clay is not very thick, for the chalk outcrops at a little distance from Windsor. At the place where the greatest movements took place, very probably, also, owing to some irregularity in the surface of the subjacent strata, the thickness might have been less than in the other parts. The water, conducted down the sides of the cylinders, then, might have softened the clay and diminished its powers of resistance; and this action, of course, would have been the greatest where the thickness was least. In this case it would appear that it would have been advisable to have stopped driving the piles as soon as they had attained a sufficient depth in the gravel, which stratum would in all probability have distributed the superincumbent weight with perfect success.

The cylinder piles used in this bridge were 6 feet in diameter, whilst the least width of the piers was 6 feet 6 inches. This would also, no doubt, have contributed to their comparative failure, for it must be evident that the proportions between the width of the foundations and of the upper structure should have been the very reverse of what took place in this instance. There are, however, considerations affecting the movement of piles, which may, perhaps, lead us to question whether it would not have been preferable to have obtained the increased surface of foundation by means of a greater number of small piles than by augmenting the diameter of those actually employed. The resistance of a pile to downward pressure is *in proportion to the perimeter exerting friction upon the ground traversed*, and is usually calculated, for soft mud, at about 45lbs. per foot superficial. It

then increases simply as the diameters of the piles, two piles of 3 feet diameter offering the same resistance as one of 6 feet. They would have required of course less material, and as they would have been driven at a slight distance from one another, they would have distributed the weight over a larger portion of the subjacent strata. In the foundations for the piers of a small viaduct upon the Chester and Holyhead Railway, traversing an arm of the sea, in the Isle of Anglesea, Mr. Stephenson adopted the plan of driving small piles of merely one foot in diameter, as in the accompanying sketch, and upon the top of them a cast-iron plate of the whole



width of the footings was placed. In the Windsor Bridge, however, the cylinder piles were arranged as below, with a broad cast-iron whaling-piece attached to the sides, and thick Yorkshire landings laid on the top, to receive the footings. The interiors of the cylinders were excavated, and they were filled up with concrete. It must, however, be acknowledged, that if there be an economy of material in the use of the small piles, yet the greater facility of driving the large ones may in many cases more than counterbalance the importance of that consideration. For, as the pneumatic pressure is in the proportion of the surfaces of the pile heads, it follows that it increases in the ratio of the squares of the diameters; comparatively speaking, there is greater facility in driving a cylinder of a large than of a small diameter.



There is a difference, nevertheless, in the mode of action of the two systems (viz., of the large and the small piles), which has not yet been made the object of a scientific investigation commensurate with the importance of the subject. The former are, in fact, means by which a series of isolated columns are carried up from what is supposed to be a solid foundation to the footings of the structure. The latter act substantially as piles, but the laws which regulate their descent, or their influence upon the subjacent strata, are unknown. We have, indeed, no data upon which to found any reasoning upon the effect of their continuous sharp edges upon the

ground; or upon the difference the smooth nature of the material of which they are made may produce in the amount of friction they exercise on the media traversed. For the successful application of the large cylinders, it would appear to be necessary that the whole of the ground in the interior be removed; for, otherwise, the concrete filling which is supposed to render them equivalent to solid columns, can never be applied close to the sides of the tubes. It must be filled in dry, and carefully driven into the corners, or the projections of the flanges in the interior will interrupt the continuity of the mass.

We would call particular attention to the question abovementioned, of the influence of the continuous sharp edge round the piles driven by Dr. Pott's system upon their bearings; for it would appear to lead to a different result from that produced by the elongated pyramidal form of the end of the common pile. Indeed, careful observations are required before any decisive opinion can be formed as to the real merits of the system, or of the best methods of applying it. The only questions, however, which can arise, are those connected with the form and the material used in the piles themselves. No doubt whatever can exist as to the immense superiority of the application of pneumatic pressure for the purpose of driving piles of large dimensions, over the usual method of what we may truly call brute force, by the use of the monkey.

It is very difficult in the present state of our knowledge of the results produced by the cylindrical piles, to form any but an approximate estimate of the amount of difference in the power employed in the respective systems. When the surfaces of the pile-heads are small, the mass of the monkey considerable, and the fall great, the ancient method of driving is the more powerful. When, however, large cylinders are used, we find that, firstly, they cannot be at all driven in that manner; and, secondly, even if they could, that it would be more economical to employ the pneumatic pressure. The power of a monkey, or its momentum, depends upon its mass and the space it traverses; that of the pneumatic pressure must depend upon the proportion of the rarefaction of the air produced in the interior of the pile, compared with the density of the external atmosphere. No sufficiently detailed observations have been made upon the application of Dr. Pott's system, to allow us to advance anything at all positive upon this portion of the subject. We, therefore, content ourselves with stating briefly the laws generally admitted to govern the ancient system of pile-driving, and of pointing out the superiorities of Dr. Pott's system in some of the details which complicate the execution of such works.

We find by experience, that the descent of a pile driven in the usual manner is proportional to the mass of the monkey, added to that of the pile, multiplied by the square of the common velocity of these two bodies after the shock. Or, representing the mass of the monkey by m, that of the pile by m', the common velocity of the monkey and the pile after the shock by u, and the velocity of the monkey before the shock by V, the descent may be stated by the following formula:

$$(m + m')\,u^2 = (m + m')\frac{m^2\,V^2}{(m + m')^2} = \frac{m^2\,V^2}{(m + m')^2}$$

Now, $V^2 = 2gh$, in which g represents the effect of gravity produced in one second, according to Whewell, $32\frac{1}{6}$ feet; and h represents the fall of the monkey. The descent is then proportional to

$$\frac{2gm^2h}{m + m'} = \frac{2gmh}{1 + \frac{m'}{m}}$$

The first of these expressions shows that the descent of a pile is proportional to the fall of the monkey; the second shows that result mh will produce a greater useful effect in proportion as the mass m is increased; and that, consequently, the economy of labour, which is in fact represented by mh, would lead us to adopt heavy monkeys, falling through heights varying with the resistance met with. A practical limit is however created by the tendency of the pile-head to split, or become spongy. The usual height given to the fall varies from 8 to 18 feet; and for the last blows it may even be made as great as 20 feet.

As a general rule, a pile should not be considered driven home, or to have "refused" until it is found that a series of ten blows from a monkey weighing 12 cwt. will not drive it more than $1\frac{1}{2}$ inch. But there are circumstances when it is advisable to cease driving before attaining such a theoretically perfect resistance; and we find in practice, that double that descent is frequently considered satisfactory. The mean sectional area of the piles is usually that which would result from the sides of a square $\frac{1}{20}$th to $\frac{1}{25}$th of the total length, and the distance from centre to centre is from 2 ft. 8 in. to 3 feet, when the load to be borne by each pile does not exceed twenty-five tons. Rondelet's rule of only bringing 490lbs. upon every superficial inch of the sectional area would induce us to regard the weight of twenty-five tons above given as slightly excessive; he, however, leaves out of account that they are considerably strengthened by the resistance of the ground to any lateral displacement. But we must allow in practice for so many disturbing actions, that perhaps, after all, Rondelet's rule is the safest guide.

Some experiments were made at Hâvre, by which it was shown that if a pile was left one metre above the ground (3 ft. 4 in. English, nearly), the diameter being 24 centimetres, or $9\frac{1}{2}$ inches, it carried 54 tons $6\frac{1}{2}$ cwt. before crushing. The piles of the old bridge of Tours crushed under a similar weight, so that it may fairly be assumed as the limit of resistance. Rondelet's rule would not have made the permanent load above 16 tons.

It has been noticed under some circumstances, that a pile which could not be further driven by the blow of a heavy monkey falling from a great height, recommenced its descent when struck by a lighter monkey, falling from a less height. This apparent anomaly is to be explained by the increase of the reaction in the ground, developed by too powerful a moving force. The movement of trepidation communicated to the pile, requires, in all cases, that occasional intervals of repose be left in the application of the

blows; and it is for this reason that, in all carefully-executed works, the driving a pile after it has appeared to "refuse" is resumed on the next day.

Dr. Pott's method of employing atmospheric pressure entirely obviates the inconvenience of the trepidation, or the reaction developed by the former method. The piles descend gradually, and without a shock, so that no vibration is communicated to them or to the ground. Unless, then, the water they conduct to the lower strata decompose these last, when once the piles have attained the limit of the "refusal," they are not likely to descend at any subsequent period, however remote.

Another advantage in the mode of driving piles by Dr. Pott's principle, is, that it enables us to place them more absolutely in the direction parallel to the resultant of the upper load. With the usual means employed, it is not possible to insert a pile at an angle of more than 30° from the vertical. As the atmospheric pressure acts in every direction, no such limit is to be fixed to the application of the cylinder piles.

In driving through hard uneven ground, it is often found, as before said, that wooden piles either split, or become spongy at the head, from the effects of the frequent percussions; and this takes place in spite of all the precautions of hooping them, or of using a cushion. This inconvenience is doubly obviated by Dr. Pott's piles; by the material of which they are made in the first place, and by the system of driving in the second; for it might, under certain circumstances, be applied to wood piles also.

We may, perhaps, be pardoned for digression from the immediate subject of our work, to mention a practical instance in which the cylindrical piles might have been employed with great success. On the Railway from Munich to Augsbourg, it was necessary to traverse a marsh, in which the solid earth was about 15 feet 6 inches from the surface on the average. The German engineers effected their object by cutting outfall drains to dry the portion to be traversed; they then dug holes, spaced alternately like the squares on a chess board, 2 ft. 10 in. apart, which were 1 ft. 10 in. square at the bottom, and 2 ft. 10 in. at the top. These were then filled in with impermeable earth, forming, as it were, so many pillars, and the roadway was formed upon them. Evidently, in any similar case, much time would be saved, and a more permanent and solid structure ensured, by the substitution of cylindrical piles filled with concrete for the pillars of earth, which, however carefully executed, must always be exposed to the danger of being undermined or diminished in bulk by the action of the water.

Finally, there is a comparative advantage attending the use of the pneumatic piles, in this—that they require far less preparatory works than the others, and that the machinery necessary for driving them is more easily transported from place to place. When the upper strata to be traversed consist of gravel, it is indispensable, if we employ wood piles, to dredge or remove it entirely, for the piles often meet with such resistances in passing through them, as either to break them or to turn them aside. As the pneumatic piles act upon a greater surface, they avoid these accidental obstructions; or at least, if they be of any large diameter, they overcome them by the greater power employed. As to the transport of the machinery, the

economy in that must be evident, when we consider the number of pile-driving engines necessary if a large number are required to be driven.

In addition to the foundations of the Windsor Bridge, the large cylindrical pneumatic piles have been employed in the erection of a bridge over the Ouse, on the Great Northern Railway; and at the present time, Messrs. Fox and Henderson are about to put in the foundations of a bridge over the Medway, at Rochester, under the orders of Wm. Cubitt, Esq. The cylinders in this case are to be no less than 10 feet in diameter. With such colossal dimensions they cease to be piles, to become in fact caissons. If they succeed, they will indeed open a new era in the history of the construction of foundations.

Nos. XIX. and XX. Bridge of the Port de Pile, on the Creuse, for the Railway from Tours to Bordeaux. (*Compiled from Les Annales des Ponts et Chaussées, October*, 1849.)

In England, the fashion for the use of iron, either cast or wrought, for bridge building, is so violent at the present day, that we are forced to seek our illustrations of modern practice and our notice of new processes of construction amongst our neighbours, whenever we examine the uses of the more anciently known materials. Iron, in its various forms, is a material offering great resources to the engineer, especially for the class of works required upon railways, in which rapidity of execution, great strength, and cheapness of construction in the beginning, are of such vital importance. The more common material, stone, is however so much superior in its lasting properties, and is so much less exposed to accidents, that it becomes almost a source of regret to observe the universal neglect with which it is treated. The age is indeed an iron age, especially in England.

The bed of the River Creuse, in the portion traversed by the bridge of the Port de Pile, consists of a stratum of gravel overlying a black clay formation, from 26 to 30 feet thick. This clay is of a schistous nature, and, although slightly compressible, it was found, after a series of experiments, that it would support the weight of the piers, if the foundations were widened out considerably. The concrete was then made about 61 feet 8 inches long, in the transverse direction to the axis of the bridge, by about 33 feet 5 inches wide; and as the clay was liable to be carried away by the scour of the river, the depth was made about 13 feet 5 inches below the top of that formation.

A large water-tight caisson, measuring at bottom 61 feet 8 inches by 33 feet 5 inches, by 13 feet 5 inches deep, was constructed, for the first pier on the banks of the river, to inclose the mass of concrete upon which the pier was to rest. The caisson had a bottom rail or sill, 14 inches square, into which uprights 12 inches square were framed at distances of about 6 feet from centre to centre. Two horizontal whales, 6 inches deep by 10 inches broad, were notched on the in and outside of these uprights; and a row of cross struts, or raking braces, was introduced below the second whale, to the foot of the next upright. Close planking 2 inches thick, well caulked, was then nailed against the outside of the uprights and the raking braces, the planks were laid hori-

zontally, so as not to interfere with the whaling-pieces. A solid close frame of carpentry was thus formed, which was further strengthened during the progress of the works, by means of cross struts, to enable it to resist the pressure of the water.

The position to be occupied by the caisson was first carefully dredged over the whole surface of the intended situation of the pier, so as to obtain as perfectly horizontal a surface as possible. A deeper trough was then formed, through the gravel to the surface of the clay, immediately under the future position of the caisson. It was then floated into its place between two barges, and lowered gradually by means of four crabs on each side until it rested upon the bottom. The water was pumped out, and then the caisson was sunk into the clay to a further depth of 2 feet 6 inches, by throwing out the earth upon which it rested, great care being taken to maintain it in its horizontal position. To prevent as much as possible infiltrations from the gravel, a risberm of impermeable clay was formed on the outside, and the under side of the sill was caulked with moss, or hay. The dryness of the interior of the coffer-dam was, however, only maintained by the use of two powerful pumps; for, as might naturally have been expected, the water forced itself under the foot of the caisson, and between the beds of the clay.

The foundations were thrown out 6 feet 10 inches in depth below the level at which the caisson was placed, and a wall, executed in coursed rubble masonry, as shown in the illustrations, was built close up to it and mounting about 4 feet 7 inches above the bottom line of the sill. The trench for this wall and the wall itself were executed before the surface of the intermediate portion of the foundation was thrown out, in order to diminish the necessity for pumping. The interior of the retaining walls was then filled in with concrete, laid dry, sets off being made in the walls to form bond with the concrete. The surface of the latter, in the positions where it passed beyond the line of the plinth, was carefully paved with stone. The concrete was executed in bands 3 feet 4 inches wide, and as far as possible over the whole surface of the foundation, before the separate breadths had been allowed to dry; the depth of the courses was from 12 to 14 inches each. All the surfaces of the concrete were well rammed with flat rammers presenting broad faces (so as to act upon a large quantity at a time), which were found to compress the concrete more equally than the narrow hammers in general use.

The caisson for the second pier was constructed upon the barges, immediately over the position it was intended to occupy, thus obviating the difficulties of floating it into place. It was completed in nine days; the immersion was effected in one day; eight days were employed in strutting the upper parts of the coffer-dam, rendering it as nearly as possible water-tight, and making the scaffolding; one day was employed in pumping, nine days for the excavations, and eleven days for the execution of the masonry and concrete to the low summer level; in all, thirty-nine days of effective work. The expense of the foundations of the first pier, leaving out of account the masonry, was about £1040; of the second, it was £1160. A coffer-dam, executed in the usual manner, would certainly not have cost more than these caissons; but the motives which appear to have induced M. Boudemoulin to employ them were, firstly, the rapidity of

execution they admitted; and, secondly, because the river Cher, of feeble depth in its ordinary state, being subject to irregular and very violent floods, the execution of coffer-dams would unnecessarily have diminished the area of its flow; and, moreover, the variations in the level of the water would have rendered the construction extremely difficult. With foundations of the nature of those met with in this river, there is also considerable danger in driving the piles necessary for an ordinary dam, because that operation is susceptible of producing movements of the lower strata, which would require them to be excavated throughout their whole extent; whereas, the foundations constructed within the caissons, take their bearings upon a large surface of undisturbed ground.

The Creuse, in the immediate vicinity of the bridge, has a fall of 7 in 10,000; its flow is of coarse rapid, and it was necessary, therefore, to protect the new masonry from its action. The floods usually rise 26 feet in the winter, but they have been known to attain as much as 37 feet 4 inches. The depth of water at the low summer level is only 2 feet 10½ inches.

A very ingenious mode of striking the centres was introduced in the bridge of the Port de Pile, for the purpose of easing them gradually and without shocks, from which cause such serious inconveniences arise in the generality of cases. In many bridges it has been found impossible to drive back the wedges towards the middle of the span, even when a sheet of metal has been interposed, owing to the enormous insistent pressure. It becomes often necessary, in such cases, to place narrower wedges by the side of the original ones, and to cut away the latter. The centre then drops suddenly, perhaps communicating its motion to the masonry; and, moreover, as it is impossible to cut away the wedges with perfect regularity, the centre becomes deformed in its descent; or one rib of a centre may be loosened before the rest, either causing distortions of the masonry, or rendering it necessary to restore that rib to its place by screw-jacks, to relieve the others still in their original positions.

As M. Boudemoulin observed, the difficulty of producing movement in the wedges, arises from the fact that the fibres of the wood in the inclined faces penetrate into one another from the effect of their load, and the alternations of dryness and moisture they are exposed to. The force which can be exerted upon them at the moment of striking the centres is never sufficient to overcome the friction arising from these causes.

Experiments were tried to ascertain whether the difficulties attached to striking the centres might be obviated by placing the ribs upon fir sills during the execution of the work; the intention being to place wedges by their side at the moment of easing the centres, and to cut away the sills, so as to leave the ribs upon the wedges, which were then to have been lowered. The maximum weight able to be brought upon one pair of wedges was 45 tons in the bridge of the Port de Pile.

Wedges of oak, whose sides were inclined in the proportion of 1 in 3½, the faces being well greased, and a plate of iron also well greased being intercalated, were placed under an hydraulic press, and exposed to an action equivalent to a weight of 50 tons, yet they did not slide upon one another,

even when struck with a large hammer. Other wedges of a compound nature, in three pieces, the top and bottom ones having one face horizontal, and the middle piece two inclined faces of 1 in 4, were tried, without producing a more favourable result. The inclination of the middle piece was carried as far as 1 in 3, on each side, but still there was no spontaneous movement.

Sacks filled with sand were then placed under the press, the cloth of which they were made being very strong, and in the experiments the sand was dried. The flow of the sand through the necks took place with the regularity of a clepsydra, and it was at any moment stopped by merely tightening the string. The weight was increased to 60 tons, but was as perfectly under control as before; even with an opening in the sack of 1 foot 4 inches long, the flow was regular, and no sudden fall occurred.

In consequence of the success of the experiments upon the sand in the sacks, the system used in this bridge was decided upon. It consisted in placing immediately over each point of support of the centres, a block of fir, on end, about 1 foot 4 inches square, the total number being 36 per arch. When it was desired to lower the centres, sacks (in common strong cloth, made open at both ends, and merely closed by a strong cord) filled with sand, were placed close against these blocks. The sacks to be placed at the points where the weight was greatest were double, and in all cases they were bound round the middle by a cloth, to increase their resistance in that portion. A small tube of cloth filled also with sand was introduced in the centre, to form, as it were, a nucleus. The sacks, when completed, were thus cylinders of about 1 foot 2 inches in diameter, by about 1 foot 4 inches long. They were placed upon a thin plank, and wedged up to the under side of the sill by fir wedges.

The upright blocks were then cut away gradually, and the weight was brought upon the sand-bags. The first movement was produced by the compression of the sand, which was observed to be about 1 inch. The mouths left at the ends were then opened, and care was taken to regulate the flow of the sand, so as to obtain a regularity of descent, by means of a small wood frame at the mouth. As soon as the centre became detached from the arch, the ends of the sack were opened to their full extent, and the flow of the sand expedited, so as to lower the whole centre about 1 foot, at which height it might either be left, or a series of wedges of the remaining distance between the sill and the supports might be introduced, to enable the sacks to be withdrawn and the descent continued.

It was found that dried sand pressed very closely upon the sacks, and occasionally destroyed them; with sand in its ordinary state they were found to resist better, but the escape was also less easy, for the pressure tended to make the sand aggregate. As an additional precaution, small blocks, varying in height as the centres were lowered, were introduced, to receive them in case of any sudden depression of the sacks; but in no case were they ever brought into action, so perfectly did the system answer. Indeed, during the whole time the operation of easing the centres was going on, no noise or creaking of the wood was heard, and it was only by measuring the

distance between the sill and the top rail of the framework upon which the centres rested, that the lowering of the former could be perceived; nor could the separation of the centre from the arch be distinguished without observing the latter very closely. It is thus evident, that the system of easing the centres followed in this instance, allows them to subside gradually, so that the voussoirs cannot assume abruptly any movement; and, inasmuch as all the bearing points sink gradually, the pressures are uniformly distributed. The system was applied for the three arches of the bridge of the Port de Pile, and also for four arches of a bridge over the Vienne, on the same railway, with perfect success; so that a sufficient number of practical experiments confirm its merits. The expense is also very insignificant, for the sacks, when single, only cost 3*s*. 4*d*., and when double 6*s*. 3*d*.; with some slight repairs the same sacks served for the seven arches.

The arches of the bridge over the Creuse remained 21 days upon the centres, after they were keyed in; they sank after the easing of the centres, in a very regular manner, a little more than 3 inches. During the execution of the arches a considerable movement took place upon the centres, to the extent of more than $1\frac{1}{2}$ inch at the haunches, which was diminished as the work approached the key, where it was not more than $\frac{1}{2}$ inch, owing to the tendency arches always have to force up the centre towards the key, even when they are loaded in that position. At the bridge in question, the weight placed at the crown was not less than 50 tons. The centre in this case was set out with an excess of height of nearly 4 inches beyond that required for the curve the arch was intended to present at the termination of the work.

The other works of this bridge, although executed with the admirable care and precision of the French engineers, do not contain anything calling for our special notice. Indeed, in the present advanced state of the Science of Bridge Building, all that remains to be done is to simplify the means of the mechanical execution. The principles have been ascertained so long since, that little room is left for the exercise of ingenuity, beyond the details connected with practice.

DESCRIPTION OF ILLUSTRATIONS,

WITH REMARKS UPON THE MODES OF CONSTRUCTION AND MATERIALS EMPLOYED.

Nos. XXI., XXII., and XXIII. Plan, Elevation, and Details of Wooden Bridge over the Seine, at Eauplet, on the Rouen and Havre Railway.—J. Locke, Esq., Engineer.

This bridge is erected over the Seine, a little above the town of Rouen, in the faubourg called Eauplet, and is situated in the immediate neighbourhood of the point of junction of the Rouen and Hâvre Railway with that from Rouen to Paris. It forms a very elegant object in a landscape of surpassing beauty, and is one of the most remarkable works on the line of railway to which it belongs, although there are few, either in England or abroad, in which so many difficulties have been successfully overcome.

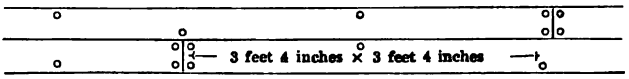
At the point where the bridge crosses the river, the Seine is very wide and deep; and, as is shown in plate 21, it is divided into two branches by an island, which diverts the right-hand channel to such an extent as to require the piers and abutment on that side to form a considerable skew with the axis of the bridge. The width of the water-way in the ordinary states of the river, and at high tides, is about 600 feet. The depth of the water is usually about 28 feet, the tide rising sometimes rather more than 4 feet. It is, however, to be observed, that the Seine, in this part of the course, is often affected by the land floods, which come down from the upper country in very great volumes, and with little warning. The dimensions of the water-way are therefore merely approximative.

The foundations of the piers were laid in cofferdams of a row of close piling on the outside, and a double row of close piling also on the inside. The space between the outer and inner rows, about 4 feet, was filled in with puddle; and the whole was well stayed, braced, and bolted, at heights of about 6 feet apart in the clear. The piles and wales were 1 foot square timber, and they were subsequently nearly all converted in the upper structure of the bridge. The foundations themselves were carried upon a bed of concrete 6 feet 6 inches thick, projecting 18 inches to 2 feet beyond the outline of the footings. To guard against any eventual scour of the river-bed, the footings and concrete were protected by sheet piling all round. It is more than probable that the works now executing for the amelioration of the Seine, between Rouen and the embouchure, may prove that such a precaution was not vain. Indeed, the very critical state of some of the bridges over the Thames, owing to the change in the regime of that river, superinduced by the removal of the old London Bridge, is such as to prove the necessity of the greatest precaution in the execution of similar works on rivers whose lower course is likely to be affected by future operations.

The upper portions of the structure of this bridge afford a beautiful illustration of the use of the laminated wooden arch, of which an example has

already been given in the previous portion of this treatise. The difference between the two designs lies principally in the spandril filling, and the greater regularity and more pleasing effect of the elevation of the Eauplet Bridge.

In this case the eight arches, of which the bridge is composed, are all of 133 feet span, with a versed sine of 19 feet 8 inches. The roadway is supported by four bent timber arches, so arranged as to carry down the load upon the pier from either line of rails independently of the other. The piers themselves are carried up in solid coursed masonry, faced with ashlar, and are 11 feet 6 inches wide at the level of the springing, which is about 15 feet above the high-water line. The arched ribs are 4 feet deep by 1 foot 6 inches wide, and are formed by bending 16 thicknesses of plank, 3 inches thick, cut out of Baltic timber, and placed concentrically one over the other, each course being fastened to those above and below it by oak trenails. These trenails were made to pass through two courses of planks into the third, at distances of about 3 feet 4 inches from centre to centre, as shown in sketch. They were made by being driven



through a mandril, in which a slight excess was given to one of the transverse diameters, so as to render them, in fact, elliptical: the diameter was about 1 inch. Fox wedges were inserted at the top and bottom to secure them in their places when driven home.

The ribs were bent upon a platform upon the ground (in workshops formed upon the island) to half the thickness of the ribs; thus dispensing with the necessity for centreing. A level floor was first formed, and posts were firmly driven into the ground, to which the planks were curved by means of strong clamps. When the beams were thus formed to half their thickness they were taken by a travelling crane and deposited in their definite positions, and the remaining depth was completed in place. The ends of the beams sprang so little when released from the clamps, that we may regard this method of assembling timber to be the most practically perfect of any we possess, for the purpose of forming curved beams of a single piece, and homogeneous throughout.

It is this comparative absence of anything like a horizontal thrust, in conjunction with the economy in the conversion of the material, which constitutes the advantage of bent-timber arches. With those formed, however, of timber of a considerable scantling, such as Wiebeking's bridges, and several of those erected in France, great inconvenience has been found to arise from the practical difficulty of curving it. The timber was either steamed, or bent by the application of heat. In both cases the quality and strength of the wood was affected; and, moreover, it was impossible to ensure strict adherence to the line of curvature. The inconveniences of the use of such scantlings were felt long ago; and we find that in 1811 a M. de Saint Far proposed a model for a bridge over the Rhine, at Strasbourg, which he intended to execute with timber ribs, formed of thin planks bent concentrically. The bridge was not constructed according to this design; but the model was deposited in the Museum of the School of the Ponts et Chaussées, where it may still be seen.

Colonel Emy, of the French Military Engineers, was the first person to apply the system of the laminated timber arches in such a manner as to fix public attention upon the subject, by the construction of the roof over the Riding Schools of Marac, near Bayonne, and of Libourne, about the year 1819. The span of the first was 66 feet English in the clear; that of the second was nearly 70 feet; they were both semicircular, and were made to form a complete truss to support the slating, without exercising any horizontal thrust, by means of principal rafters tangential to the curves, tied to the latter by means of radiating clipping braces normal to them. The ribs were bent complete, without trenails, and were maintained in their form by stirrups subsequently placed and passing round the whole system every 5 feet apart, and by bolts in the intermediate spaces every foot apart with broad washers. The normal clipping braces were also about 5 feet apart from centre to centre.

Colonel Emy tried the model rib for the roof of the school at Marac (which was composed of 5 courses of fir planks, each about $2\frac{3}{16}$ inches in thickness), by suspending 11 tons of pig iron from the points where the clipping braces were to be placed. The effect produced was to bring down the crown, and to force out the arch in the haunches to the extent of 2 inches. The feet, although left free, had not moved, nor had the lower diameter in any way been augmented. He concluded from this that the horizontal thrust was insignificant; and, at the same time, he drew the further conclusion that these timber arches required to be strengthened at the haunches, and lightened at the crown and springings. There can be no doubt but that it would be advisable so to lighten the crown, by omitting one or more courses of planks; but practically, in bridge building, the omission of those near the springing would be a source of great inconvenience. In the arched ribs executed for the Eauplet Bridge the courses of planks at the top and bottom might have been stopped a little beyond the third stirrups, counting from the piers on each hand, with considerable advantage. The real strength would have been the same, for that of course is measured at the weakest point; and the arch would have been lighter and contained a smaller cubical quantity of timber.

Navier differs from Colonel Emy, however, in his opinion of the absence of horizontal thrust in these laminated arches. In a very elaborate article, inserted in the "Annales des Ponts et Chaussées" for the year 1831, he demonstrates that, "even on the supposition that such assemblages of planks become, in fact, a single and homogeneous piece, they must exercise an effort to overthrow their points of support, acting in a horizontal direction, which, however small it may be in comparison, is still sufficient to require to be taken into account. It is true that in the upper part of the framing other pieces are introduced, by means of which a sort of truss is formed in such a manner as to resist any change of shape in the arch itself; and thus to a certain extent, by converting it into a rigid beam, to diminish its horizontal thrust. But as, on the other hand, the load is not evenly distributed over the whole length of the arch, and by means of this very identical upper framing it is more concentrated in its action upon the highest portion than upon the springing, the framing may be considered as augmenting the thrust in this manner as much as it counteracts it in others." Navier concludes that, for this reason, it would not be safe to leave out of

account the horizontal thrust in designing large works in which the laminated timber arches are to be employed.

There is little reason to question the correctness of Navier's opinion, regarding the question simply as a mathematical one, and at any rate, an excessive caution in such cases is a defect hardly to be found fault with. But the fact is, that Colonel Emy was correct when he stated that the description of arch under consideration did not exercise any lateral effort worth notice. An illustration of this was offered by the bridge at Eauplet. In the revolutionary riots of 1848, the mob set fire to the bridge in several places, and succeeded in burning one of the land arches. When it fell, of course the piers were abruptly deprived of the counteracting resistance to the thrusts of the arches remaining in place; yet they resisted, nor did they exhibit the slightest symptom of movement. A very different result, however, took place with the bridge at Asnières, on the St. Germain's Railway, which was destroyed at the same epoch. This bridge was composed of 5 arches of 100 feet span each with 15 feet $8\frac{1}{2}$ inches versed sine, the thickness of the piers being about $\frac{1}{8}$ of the span: it crossed the river at an angle of about $76\frac{1}{2}°$, and was made wide enough to receive 3 lines of rails. There were 5 ribs formed by bending 4 courses of squared timber measuring 1 foot on each face; or the rib was 4 feet deep by 1 foot wide. The upper structure was carried by normal clipping pieces filled in with St. Andrew's crosses. When the mob set fire to this bridge, and, with all the horrible exultations of fiends over the success of their mischief, were dancing on some part not then in flames, one arch, having been consumed, fell, and all the others—piers, mob, and all—toppled over into the Seine.

It appears from this, that the elongation of the fibres in large pieces of timber, such as were employed in the St. Germain's Bridge, kept the elastic force of the wood in continual action. So long as this thrust was balanced by a similar and equal one on the opposite side of the pier, no danger could arise; but the fall of the St. Germain's Bridge illustrates the impossibility of obviating the danger arising from the tendency of the timber to resume its form. This tendency must also exist to a certain extent with the ribs formed by bending planks of small thickness; but as the differences between the extrados and the intrados of each plank are insignificant, it must take place in a very inferior degree. The system of trenailing the different courses of planks, by preventing their slipping upon one another, also assists to counteract the tendency to resume the original form. It is evident that the upper courses could not resume the horizontal line in a laminated arch, like that of the Eauplet Bridge, without extending the lower ones by a quantity equal to the difference in their developments. The small springing at the feet, which does take place when these arches are released from the clamps in which they are put together, appears to be attributable to the imperfection of the execution of the manner of trenailing the planks. If these could be made to fit with mathematical precision, it is more than doubtful if any movement of this kind would occur.

After the fall of the Barentin Viaduct, upon the same line of railway as the Eauplet Bridge, this last was tested by the French Government engineers, with a dead weight of about 224 lbs. per foot superficial. This was certainly a severe test, because in a railway bridge the strain to be supported is never in

proportion to the surface of the floor, especially when the span exceeds certain limits. However, no movement was observed, and had the weight been tripled the bridge would have supported it. The testing of the bridges on this line of railway gave rise to several discussions fraught with great interest to the science of engineering, to some of which we shall recur in our notice of Illustration No. 24.

Before quitting the subject of the Eauplet Bridge, we may observe that the planks bent the more easily in proportion as they were longer, fresher from the saw, and more devoid of knots. When they are cut from Baltic timber, in fact, they are more suitable for such purposes than when they are simply planks, or deals, ready prepared to the thickness. The planks used directly after they left the saw were found to possess the necessary degree of freshness, the more especially when they were cut from large scantlings which had very frequently been floated up to the works, and thus accidentally wetted. When the timber was very dry, or short in its grain, it was necessary to moisten it in order to avoid its cracking. In an arch of 133 feet span there were from 4 to 5 butt joints. It was found that from 3 to 4 men could bend the planks from one post to another, when they were placed about 6 feet apart.

In a paper Mr. Vignolles read before the British Association for the Advancement of Science, he stated that the comparative expense of a timber viaduct of large span was not above one-third of that of a similar work executed in stone. In confirmation of this we may state that the Eauplet Bridge, executed by Messrs. Brassey and Mackenzie, under the orders of Joseph Locke, Esq., did not cost more than 57,800*l.* sterling; or about 50*l.* 10*s.* per foot forward, measuring from abutment to abutment; or a little more than 2*l.* per foot superficial, measuring the length between the abutments, and the width between the parapets. If we compare these results with those obtained from similar calculations upon bridges executed in the same conditions with respect to the waterway, and the depths of the foundations, the economy of this method of construction must be evident. In our colonies, where commercial relations have to be established *after* the railways are made, considerations of first outlay are of vital importance. Even in our own country it is more than questionable whether the mania for constructing monuments for the admiration of posterity has not been fatally exaggerated, at least for the interest of the shareholders in such undertakings. Be that as it may, there can be no doubt but that it is preferable, in new countries, to adopt the mode of construction which requires the least outlay at first, even at the risk of expending a considerable sum for the renewal. Upon this subject we may remark, that in England it is usual to calculate the duration of wooden bridges at about forty years. On the Continent their duration has rarely exceeded thirty years; nor would it be safe to calculate upon more than that in face of the carelessness which marks the execution of all works of maintenance upon railways, especially in matters connected with painting or other precautions to ensure the duration of timber.

Two other important lessons were to be drawn from what occurred during the execution of this bridge. Firstly, the arches in the land abutment on the towing-path side were executed without any invert, or any connection between the foundations of its piers. Consequently, when the embankment was brought up to this

abutment, its weight acting upon the alluvial soil of the Valley of the Seine forced in the foot of the left-hand pier and opened the arch at the crown. Similar accidents have occurred so frequently that it seems almost unnecessary, at the present day, to warn engineers of the possibility of their happening again; but the tendency of the times decidedly is to risk so much that we may be excused for calling attention to the necessity of rendering the whole of the foundations of an abutment parts of one and the same system.

Secondly, in bringing the embankment across the alluvial plain up to the bridge, it was deemed advisable to execute the backing of the abutment with earth taken from a side cutting formed, it is true, at some distance from the immediate line of the railway. When the remaining part of the bank was completed it was found that the weight of the new material forced out the foot of the ground near the side cutting—that in fact, to use the workman's phrase, it caused the subsoil to spew up—to such an extent as to entail a very heavy loss upon the contractor. In executing such embankments upon similar lands it would thus appear to be a matter of vital importance to leave the upper stratum intact as much as possible. This precaution may not suffice to prevent a compression of the subsoil; but the tendency of the strata to slip on one another is not, so to speak, provoked to the extent it must be when the resistance to the lateral movement of some of them is destroyed. The same compressibility and tendency to movement of the alluvial strata of all valleys of rivers, should also lead engineers to be careful in isolating entirely the foundations of the edifices they may have to erect in such positions. Many unsightly crevices, and many serious failures, may be attributed to the neglect of this simple precaution.

All the timbers of this bridge were prepared by steeping them in a solution of the sulphate of copper, according to Margerry's patent. The price of the laminated arches, including the preparation, was about 4*s.* 5½*d.* per foot cube, in place. The time employed in the erection was more than two years; but there was no particular reason for expediting it, or it might have been completed in considerably less time.

No. XXIV. Plans, Elevation, and Sections of Malaunay Viaduct, on the Rouen and Havre Railway.—J. Locke, Esq., Engineer.

The interest attached to this viaduct in an engineering point of view does not so much depend upon the work itself, or the character of the design, as upon the discussions which took place respecting it, the experiments and trials it was submitted to, and its connection with the history of some other works upon the same line of railway.

Amongst the numerous heavy works upon that line, which we have before mentioned to have been attended with many difficulties, there were several viaducts of colossal dimensions, of which those of Malaunay, Barentin, and Mirville were the most remarkable. That of Malaunay, represented in our illustration, consisted of eight arches of 50 feet span, with piers whose greatest height was 66 feet nearly to the springing, and 26 feet more to the rails' level. The Barentin Viaduct had 27 arches of the same span, and piers whose height was about 86 feet from the concrete to the springing of the arches, the height from the same point to the

rails being 112 feet. The Mirville Viaduct was longer, and with a greater number of arches, but their span was only about 30 feet; and although the extreme height of some of the piers was greater, the mean of the whole was less than at Barentin, which was also entirely built on a curve.

The Malaunay and Barentin Viaducts were constructed with bases, or plinths, of a species of indurated chalk (extracted in the neighbourhood of Rouen), as far as the level of the set off. The outside was executed in coursed stone, such as might almost have been called ashlar. The interior was filled in with rubble, without bond; and the whole of these plinths, with the superincumbent brickwork of the piers, was bedded in mortar, made of common chalk lime, without the presence of any ingredient able to communicate to it the power of setting rapidly. The upper parts of the piers were executed with the hollow flues, indicated in the drawing of the Malaunay Viaduct, with discharging arches to relieve the haunches. The Mirville Viaduct was executed entirely in brickwork, and differed in its details from the others. It was, in fact, a copy of the Ouse Viaduct on the Brighton line, excepting that all the ornaments were omitted. The piers were lightened by transverse openings, not by hollow flues.

During the summer in which these works were executed much rain fell, retarding still more the setting of the mortar. However, before the winter closed in, the Malaunay Viaduct was completed, and the last centres of that of Barentin were struck. The ballasting was even commenced upon the latter, when, before daybreak on the morning of the 10th of January, 1845, without any warning of sufficient importance to indicate the approaching catastrophe, and almost without witness, the whole structure of the Barentin Viaduct fell to the ground, hardly leaving one stone above another. The arches were broken clean off from the abutments, and it would almost be impossible for imagination to conceive a more perfect destruction than had been wrought in the intermediate distance: the viaduct had disappeared, literally "like the baseless fabric of a vision."

Much interest was excited as to the cause of an accident entailing so serious a loss upon the Company, and which might so easily have been fraught with fatal consequences to human life. The public investigation, however, was powerless before the admission of the contractors that the blame was theirs, and that they were alone responsible; but in the interests of science we may proceed further, especially as the lapse of time since the occurrence of the accident has so far rendered it a matter of history as to justify our endeavouring to draw all the information possible from it.

Firstly. The execution of the plinths in masonry of the kind employed both at Malaunay and Barentin was very ill advised. The average crushing weight the chalk was able to resist could hardly be taken at more than 250 lbs. to the square inch, when that weight acted instantaneously. But the power of stones to resist a permanent load is very different from that they exercise under momentary strains, and it would not have been safe to have adopted as the outside safe load a weight exceeding 80 lbs. per inch superficial. In rubble masonry even this limit far exceeds what should in prudence be applied, especially when, as in this case, no particular pains were taken to bond the work together. It is usual to adopt one-tenth of the immediate crushing weight, nor does the precaution appear exaggerated. In the Barentin Viaduct, however, the upper structure

acted upon the plinth with a weight equal to about 59 lbs. on the square inch, instead of 25 lbs., the theoretical safety limit.

Secondly. Had the masonry of the plinths been executed in hydraulic lime instead of common chalk lime their fate might have been different, although even then the risk incurred would have exceeded what is ordinarily deemed prudent. But with so large a mass of chalk lime as was here employed it was impossible that the setting could take place in the interior. When the viaduct fell, the mortar near the middle of the plinths was as fresh as the day it had been made, nor would it have become solid perhaps for centuries. The chalk near Barentin is a very pure carbonate of lime; and, as is known to everybody who is in the slightest degree acquainted with the nature of that material, it was utterly worthless as a source of supply for the mortar of such a construction as the viaduct, in which the mass of the masonry would effectually oppose itself to the absorption of the carbonic acid gas from the atmosphere by the mortar in the interior. The very cold wet summer of 1844 was also unfavourable to its setting. Indeed the only wonder to be felt about the results of works carried on in such a manner is, that they should have kept together so long as they did.

Thirdly. The economy of carrying up the flues in the interior of the piers was also a source of danger. Doubtlessly a given cubical quantity of material will support a greater crushing weight when disposed as a hollow tube than when it offers merely a solid block. But in such cases the tubular sides require to be tied together at regular distances, to prevent any tendency to buckling. The structure of the reed will best illustrate the principles upon which such flues or hollow tubes should be constructed. At Barentin and at Malaunay this precaution was not taken, nor was a substitute offered by the introduction of any bond in the piers themselves, either by the use of hoop iron or of courses of stone. It may fairly be questioned whether in fact the lightening of the piers in the manner here done was not a dangerous manner of increasing the load in the middle of the height of the pier without any counterbalancing advantage. The weight upon the impost was in fact about 56 lbs. on the inch superficial, whilst in the centre of the pier it was 77 lbs. per inch.

The fall of the viaduct seems, however, to have immediately arisen from the weight of the upper structure bursting out the plinth of one of the piers. A crack had been noticed on the previous evening upon the one which commenced the movement, and it had been marked, to verify if any progress would take place. As was before said, however, the whole structure came to the ground before daylight, and before anybody could be summoned to observe its disappearance. The plinth which first gave way was observed to have been blown out as perfectly as though a charge of gunpowder had been exploded in it. The arches right and left of it were drawn down in its fall, and all the rest followed like a pack of cards. The total overthrow of all the arches affords a singular commentary upon M. Navier's remarks respecting the horizontal thrust of homogeneous rings, for it is only upon the supposition that such an action does take place that we can account for the fall of all of them. The sudden development of an active force of this kind, acting with the great leverage resulting from the height of the piers, must have led to the overthrow of the latter. The vulgar notion that semicircular arches exercise no horizontal

thrust, at least during the period the materials are able to move freely upon one another, is fully controverted by what took place during the fall of the Barentin Viaduct. Of course this must be self-evident to a mathematician, because no arch whose extrados and intrados are concentric can be an arch of equilibrium; but it is desirable to call attention to the popular opinion upon the subject, if only to manifest its error. Moreover, the necessity of intermediate abutments was, perhaps, as painfully demonstrated in this case as it is possible to conceive it to have been; for, in spite of all the errors in the construction of the piers, the resistance of the Malaunay Viaduct would lead us to suppose that if such had existed the extent of ruin might have been controlled or limited.

After the fall of the Barentin Viaduct the whole of the works of the line were subjected to a very rigorous inspection, and subsequently to a series of proofs, such as we English engineers are little in the habit of hearing of. The Malaunay Viaduct was found to exhibit signs of movement in the plinths similar to those which had taken place in the Barentin Viaduct, and their effects were immediately guarded against by the introduction of cast-iron shields on the outside, and wrought-iron tie bars, traversing the mass of the masonry both longitudinally and transversely, which screwed up against these shields. A species of wrought-iron cradle was thus formed round the plinths; but it is beyond doubt that such a course would have been perfectly useless if the tendency to movement had existed here in the same degree in which it existed at Barentin. The height of the piers was less, and it may be that the lime used possessed greater hydraulic properties. The chalk formation differs sufficiently within, comparatively speaking, short distances, to warrant our supposing that the lime furnished by kilns only two miles apart, might differ very essentially. Be that as it may, the movements of the piers did not extend after the introduction of the system of consolidation, whether owing to it or to any original difference in the materials employed.

The Mirville Viaduct, which also had been executed in chalk lime, exhibited signs of weakness as alarming as the others had done. The plinths immediately under the solid parts of the piers were found to have been compressed by the weight of the superincumbent mass of the brickwork, and in many cases they were split nearly from the top to the bottom. The remedies adopted to stop this action were to take down a portion of the piers so affected, to rebuild them with brickwork set in hydraulic mortar, and to fill in the discharging arches solid. Two of the intermediate arches were filled in with transverse walls, so as to convert them substantially into intermediate abutments. After these precautions had been taken the movements ceased.

The Barentin Viaduct was rebuilt entirely in brickwork; the dimensions were increased; the flues were suppressed; and, what ought to have been done at first, nothing but hydraulic lime was allowed to be used. The exertions of the contractors were absolutely marvellous, for the whole edifice was rebuilt, from the foundations upwards, in less than nine months. Indeed, it would be impossible to praise highly enough the honourable manner in which Messrs. Brassey and Mackenzie came forward to accept all the responsibility of the failure, or sufficiently to admire the energy with which they effaced all traces of the misfortune.

In the mean time public opinion, which in France, unfortunately, is always ready to take part against companies, especially when conducted by foreigners, had been still more excited by the fall of several of the smaller works upon the Rouen and Hâvre Railway, which, in almost all cases, were attributable to the use of chalk lime instead of hydraulic lime.. The Government engineers were therefore, almost in their own defence, obliged to exercise the utmost rigour in testing the different works, before authorizing the circulation upon the line. Little doubt was felt as to the solidity of the Eauplet Bridge, and, as was before stated, a load of 1000 kilogrammes per metre superficial, or about 224 lbs. per foot superficial, was deemed sufficient to prove its solidity. The viaduct of Mirville was judged to have shown greater symptoms of weakness, and was therefore proved with a dead weight of 448 lbs. per foot superficial nearly; whilst the Malaunay Viaduct, the most dangerous of all, was proved with no less than 672 lbs. per foot superficial of the roadway, measured between the parapets and the abutments. The engineers and the directors of the company protested longly and loudly against the exaggerated nature of the last proof; but they were forced to yield,—under protest, it is true,—and the weights were applied as prescribed by the engineers of the Ponts et Chaussées. The results were that none of the different works moved, and the line was at length opened.

The effect of the dead weight thus superadded to the weight of the structure itself, in the Malaunay Viaduct, was to bring a load equal to 99½ lbs. per inch superficial on the weakest portion of the piers. Vicat had previously calculated that the extreme safety limit to which brickwork, executed with rich lime, could be loaded after fourteen years, was about 85 lbs. per inch superficial. The Malaunay Viaduct, after only eighteen months, resisted the greater weight; but even though it did so successfully, the risk run was very unjustifiable, inasmuch as the extreme rolling weight, even supposing the trains brought upon each arch only to have consisted of locomotives and tenders, could not have produced a greater load than 79 lbs. per inch superficial, after allowing for the development of the forces resulting from the rapid movement of the trains.

The danger of these exaggerated loads lies in this, that they are far from acting uniformly over the surface of section upon which they are supposed to bear. In the first place, the mortars set with greater rapidity towards the exterior of the masonry, and that portion of the work is always executed in a superior manner to those which are out of sight. However, it has been demonstrated that it is possible to load comparatively speaking fresh brickwork with not less than 99½ lbs. per inch superficial, even when executed in common chalk lime.

Recapitulating the lessons to be derived from the accidents which occurred in the execution of these works, we may observe, that there is always great danger in the execution of the lower parts of piers of considerable elevation in a material less resisting in its nature than the upper structure, if that material be not prevented from spreading laterally, as is the case with the concrete foundations of all works.

When hollow tubes are employed, care should be taken to bond the sides together at distances sufficient to prevent the buckling of the latter. The precise distances have not been ascertained, either by analytical investigation

or by direct experiment; but from analogous natural constructions we may assume that about twelve times the opening is about the extreme space which ought to intervene between the cross ties.

Inasmuch as, even with semircular arches, although they are executed in a manner to render them perfectly solid, homogeneous rings, there still exists a lateral thrust capable of overthrowing their piers if these be of feeble dimensions and of great heights,—it is absolutely necessary, in a long series of arches, to interrupt the action which might be suddenly developed by the fall of any of the intermediate ones, by the insertion of some wider piers to act as abutments. In railway bridges or viaducts these piers might easily be made to co-ordinate with the general design by being converted, in the upper portions at least, into depôts for plate-layers' tools, or into guard houses. The absence of such wider piers is a serious defect in many of our modern viaducts, and numerous accidents are to be attributed to this apparently simple cause.

Finally, we cannot dwell too much upon the necessity for executing the works of all buildings of great height, or of considerable dimensions, in the best hydraulic lime, such as is capable of setting, even under water, in about a fortnight. The use of chalk lime is worse than a folly, since the action of the different kinds of that material have been so well ascertained. The indifference of many of our engineers in the employment of this material is, perhaps, one of the worst features in the state of professional practice in the present day.

No. XXV. PLAN, ELEVATIONS, AND DETAILS OF A SUSPENSION BRIDGE EXECUTED UPON THE SEINE, WITH CABLES OF HOOP IRON, UNDER THE ORDERS OF MESSRS. FLACHAT AND PETIET. (*Extracted from Les Annales des Ponts et Chaussées*, 1842.)

Many inconveniences have been found to be attached, both to the ancient system of execution of the suspension cables of bridges in wrought-iron bars, and to the modification so frequently adopted in France by the use of iron-wire; at the same time that both possess advantages peculiar to themselves. Messrs. Flachat and Petiet, in the execution of some foot-bridges, endeavoured to discover an intermediate system, by means of which, whilst avoiding the inconveniences of those already in use, they might obtain the advantages of both of them. After several essays upon a small scale they were allowed to construct the bridge now under consideration; and the success which attended its construction was certainly sufficient to justify the reception of their mode of executing suspension cables as one of the legitimate resources of the engineer in the ever-varying circumstances which occur in practice. The hoop-iron cables, indeed, are liable to many objections, as we shall have occasion to remark hereafter; but they afford a valuable substitute for more perfect means of execution, in many cases where celerity and economy are more to be sought for than theoretical perfection.

The bridge of Suresnes, as shown in the drawings, has a distance of 500 feet between the faces of the abutments, with two piers in the river, 203 feet

3 inches apart, from centre to centre. The curvature of the chains has a versed sine equal to one-tenth of the chord, in the centre bay; the curve of the side bays is formed principally by half an arc on each side, whose versed sine, measured on a line perpendicular to the horizon, is rather more than one-tenth of the whole arc. The floor of the bridge consists of a carriage-way 16 feet 8 inches wide, and two foot-paths, each 2 feet 9 inches wide; giving a total width between the parapets of 22 feet 4 inches.

The chains of each bay are peculiar to it, in such a manner as only to support the effort exerted upon the bay itself. They pass over the piers, and are attached to the masonry at a point 3 feet 4 inches above the level of summer water. The piers then have only to resist an action tending to turn them over on one edge, such as can be produced by a single bay. We have thus six cables in the whole of the bridge, which are made in one length from the respective points of attachment, going down at once to the bottom plates, and dispensing with all kinds of tieing-down bolts.

The strain to which the central bay could be fairly exposed was calculated at 182·825 tons; that of each of the side bays, at 170·347 tons. The engineers of the Ponts et Chaussées had required that the cables should not be exposed to a greater strain than 19,913 lbs. per inch superficial of the sectional area; their dimensions were therefore fixed at $3\frac{3}{32}$ by $3\frac{1}{8}$ inches for the central bay, and $3\frac{3}{32}$ by $3\frac{1}{5}$ inches for the side bays, which gave rather more than the absolute resistance required.

The horizontal distance apart of the floor joists is about 4 feet 7 inches corresponding with the spaces between the joints which receive the suspension rods. From this reason, however, they are further apart, in proportion as the elements of the cable become lower.

Each cable is composed of 8 hoops $3\frac{3}{32}$ of an inch wide, or, to use the decimal notation, 3·093 inches by a mean thickness of 0·39375 inch in the centre; and of the same number of hoops of the same width by a mean thickness of 0·38 inch in the side bays. The length of each hoop is from 46 feet 8 inches to 50 feet, and corresponds to the distance of ten joints. Each joint serves to fix the ends of two hoops which finish, and of two which commence; they are of cast iron, in two pieces, according to Fig. C, Illustration No. 25, the line of their junction corresponding with the axis of the cable. They are brought close up to the hoops, which, consequently, they bring forcibly together, by means of four rivets placed hot. The two portions of the joint are maintained in their exact position, opposite to one another, by tenons from the upper portion, which pass into a corresponding mortice in the lower one, and resist the strain which draws the two portions of the joint in opposite directions.

The extremities of the hoops which are to be fastened to the joints are bent up against their vertical faces. The angle they turn against is rounded, to avoid any strain upon the fibre of the iron. They are then fastened to the joints by means of two small bolts about $\frac{3}{8}$ inch diameter, with screws, and a washer, to take the two bolts. In the bottom of the cast-iron joint a hole is left with a rim round it to receive a wrought-iron tongue, to which the suspension rods are subsequently attached. The line of junction of the two portions of the joints is hidden by a patera or a lion's head.

Owing to the disposition of the hoops in these cables it was found necessary to keep them entire in a vertical plane; and, in carrying them over the piers, the centre bay was made 5½ inches wider on each side of the axis of the bridge than the side bays. No joints were placed in the distance of about 9 feet 2 inches in which the cable passed over the circular part of the saddle, so as to enable them to be brought as closely together as possible, and to simplify their movements upon the top of the piers. The saddle was formed, firstly, by attaching a plate of wrought iron over the whole of the bearing surfaces of the tops of the piers. A stouter bar of iron was then riveted to it in the positions of the passage of each cable, carrying nine small cast-iron rollers. A concentric plate, on which were three shoes, without any projection on the under side, was made to receive the hoop cable in the part where it bore upon the rollers, thus dispensing with one intermediate cast-iron joint. The plate forming the base of the saddle rested immediately upon the stone; the stouter bars were riveted upon it for about $\frac{2}{3}$rds of its circumference, their distance apart being 5½ inches.

The passage over the land abutments is effected in a similar manner, excepting that there are only three rollers. The illustrations will dispense with further details on this subject.

The ends of the cables are very considerably strengthened at the point of their passing round the anchor heads. The number of hoops is augmented to 36, instead of 20, as it is in the other parts of the doubled cable in the well. Four of these extra hoops terminate at the last clipping joint; the remaining twelve are carried on into the body of the cable and are lost as they proceed upwards, alternately on the different sides of the axis. The joints are brought closer together in the portion of the chain thus strengthened, not being more than 6 inches apart. In the last a rivet is made to pass through the whole system, in order to prevent any tendency of the hoops to slide upon one another.

The thickness of the anchor plate is $3\frac{1}{16}$ inches, with ribs projecting 2 inches in addition. A rectangular hole is provided for the passage of the eye of the cable. The bottom key is in cast iron, and semicircular; the others are of wrought iron, the one nearest the plate being made thicker than the others, and with a projection on each side, to maintain it invariably in its position.

The hoop iron for these cables was sent from the factory in lengths of from 46 feet 8 inches to 50 feet, as before mentioned, doubled up in parcels about 6 feet 6 inches long, in four turns, with a mean curve at the points of bending of about 10 inches radius. They were all straightened cold, and were not found to have been affected by the curvature. To remove any trifling irregularities which might still remain, the separate hoops were bedded upon a table; and after being thoroughly dressed and carefully scraped, so as to get rid of any scales or rust, they were painted with the same description of black paint used in the preparation of the chain cables.

The cables were formed on a platform, on the ground, made with the joists intended to be subsequently employed in the bridge. At the points of curvature corresponding with the piers and abutments, the platform was made stouter in order to resist the elastic force of the iron, which necessarily produced greater effect at those points. Cleats were nailed upon the joists in the inter-

mediate portions, forming a groove of the dimensions of the cable when complete, leaving a little play during the putting the cable together. In the larger curves it was not necessary to exert any great force to bend the hoops; over the piers and abutments, however, they required to be beaten into their definite form; for the elasticity of the iron did not allow it to assume so sudden a curve without producing a violent effort to straighten itself again, and, in this manner, it sometimes disturbed the platforms in the other portions. As soon as the cables were thus temporarily formed, wedges were driven into the grooves of the platforms, to keep them together until the joints were placed.

These joints were inserted as follows:—stirrups, with keys and wedges, were made to clip the cable very tightly, a little on each side of the definite position of the joint; and an intermediate stirrup was placed between each space to ensure perfect regularity in the hoops throughout. The cast-iron joint was then applied, and riveted up, and the stirrups removed. The ends of the hoops were subsequently bent up against the face; the holes for the bolts were punched cold; the bolts were inserted; and the ends of the hoops cut off. To avoid splitting the ends of the hoops, it was found advisable to leave them rather longer than was absolutely necessary. When the workmen had become acquainted with the nature of the work, the execution of these cables proceeded very rapidly. At the latter portion of the time it was found that eleven to twelve men could make a cable 340 feet long in about four days.

The eye for the anchor was always formed when the rest of the cable had been completed, the semicircular collar at the bottom and the wedge separating the cable being offered in the respective positions they were to occupy in execution. The hoops were bent round the last collar cold, and without the use of a hammer.

As the yard in which the chains were put together was about 500 feet from the river, it became necessary to transport them upon a series of rollers, seventeen in number, placed from 16 to 17 feet apart. The cables were placed on edge upon the rollers so as to preserve their rigidity vertically, but to admit of their bending horizontally. The weight was about 6 tons 12 cwt. for the longest cable, which was 334 feet long, or about $44\frac{47}{100}$ lbs. per foot lineal. They required from fifteen to twenty workmen to lead them from the platforms to the river side, where they were embarked upon a string of boats fastened together, and floated to the positions requisite for hoisting them. The cables of the land openings were placed first, because they were attached to the piers within those of the central span. The ends which were fastened to the piers were those which were fixed first.

It was observed that the operation of moving and hoisting the cables had caused the hoops to open in places. As soon, however, as the suspension rods and the roadway were placed these openings disappeared, and the cable assumed the character it was intended to offer, namely, a long bar without solution of continuity.

A defect of rather a serious nature was observed in the cast-iron joints, namely, that they frequently broke under the operation of riveting, or subsequently, during the trials to which the bridge was exposed. Messrs. Flachat and Petiet proposed, as a remedy for this, that they should be replaced by flat wrought-iron hoops passed round either twice and returning again up one side, or three times

with the same return, so as in fact to go round the cable 2¼ or 3¼ times. They were to be bent hot, holes were to be drilled through the faces which formed the two extremities of the joints, and screwed pins inserted to prevent any movement when the load should be applied. We may remark that this mode of obviating the difficulty does not seem very satisfactory. The joint may be strong enough as proposed; but it is complicated, and by no means so elegant as the original form. Still the difficulty of securing sound castings, or perfectly even surfaces, renders the use of the cast-iron joints very objectionable.

In the article by Messrs. Flachat and Petiet, which is inserted in the *Annales des Ponts et Chaussées*, those gentlemen give in detail the calculations which induced them to fix the dimensions, not only of the joints, but also of the rivets and bolts, with very abstruse observations upon the friction exercised by the hoops upon one another. Really the care with which these investigations were made, and the minutely-detailed character of the experiments entered into to confirm the results derived from them, were highly curious; but for all practical purposes we may content ourselves with receiving the facts to be as these gentlemen assert, without following them through all their calculations. It is sufficient, perhaps, to state empirically, that if the joints are executed in cast iron their width should be 1½ time the height of the cable, if in wrought iron 1¼ of the same dimension; and the rivets for cables of the dimensions employed in this case need not differ materially in their diameter from a little less than ⅛th of the height.

A series of experiments was also made for the purpose of ascertaining the real longitudinal strength of the hoop iron. From the mean deduced from seventeen essays, it appeared that the breaking weight, acting instantaneously, varied from one equivalent to between 49,932½ lbs. per inch superficial to 56,174 lbs., showing that its resistance is at least equal to that of the best fibrous bar iron. The hoops that supported the greatest longitudinal strain were also those that extended the most; but the extension was not sensibly apparent until the strain exceeded 35,000 lbs. per inch superficial of the sectional area.

Cables put together in the manner it was proposed to adopt in the execution of the bridge were then submitted to the action of the hydraulic press. The average results obtained from four thus broken showed—first, that the resistance to a longitudinal strain was equivalent to a force of 42,677 lbs., acting instantaneously.

Secondly, that no important elongation took place until the strain approached 35,000 lbs.

Thirdly, that the joints resisted perfectly, and that by calculating their dimensions upon the supposition that they would be exposed to three times the longitudinal strain the hoop iron is supposed theoretically to resist, every security exists for the use of cast iron.

Fourthly, that the method of forming the eyes was also perfectly satisfactory. Indeed Messrs. Flachat and Petiet were of opinion that, instead of augmenting the section by ⅛ths of what it is in the other portions of the doubled cable, it would have been sufficient if it had been made merely from ⅛th to ¼th more.

Now, in a careful examination of the different systems employed in the

manner of forming the suspension cables of bridges of which they form the characteristic features, we find that the advantages attached to the use of bar chains are that, inasmuch as they present a smaller surface for the action of the oxygen of the atmosphere, they possess the greatest durability, and that, if proper precautions be observed by painting them, their durability may almost be considered unlimited.

Iron wire has a greater power of resistance to longitudinal strains than bar iron; but it rusts with great facility, which must necessarily diminish its strength, and in a space of time, more or less long, bring it down to that of bar iron. We may also observe that, in addition to this inconvenience, iron-wire ropes can never be executed with the perfection requisite to prevent their elongation under a load permanently applied. However carefully prepared, the wires are never completely straightened, nor do they assume their definite arrangement until the permanent load has acted upon them for a considerable time. The advantages of iron-wire cables are, on the contrary, their greater resistance, their lightness, the absence of joints (which act very injuriously, not only by their weight, but also by diminishing the solidity at the eyes), and a greater comparative security, without its being necessary to prove every separate part. Finally, they are much more economical than the chain cables, and are put together with far greater ease.

The preference would, therefore, be unreservedly given to the iron-wire cables, were it not for the danger arising from the oxidization and the elongation of the cables. Recent circumstances connected with the fall of some of the French suspension bridges, executed in this manner, show that, far from being exaggerated, the fears previously entertained from this cause were, if at all, rather underrated. In the subsequent portions of this notice, and in our description of the Oporto Bridge, we shall revert to this question more at length.

The hoop-iron bridges constructed by Messrs. Flachat and Petiet are executed under conditions which remove them from either of the above categories. They possess to a certain extent the advantages of the iron-wire cables, of being composed of a re-union of a great number of elements; and to a certain extent they participate in the durability of the bar chains. Like the wire cables, also, they avoid the necessity for the joints of the other description of suspending chains, or at least the proportionate weight of the joints is, comparatively speaking, insignificant.

Examining the subject more closely we may consider the different systems under the following heads:—

1st. The absolute resistance of the materials, and the load they are exposed to on trial.
2nd. The comparative weights of the cables.
3rd. The surfaces and volumes of the said cables.
4th. The absolute resistances of the whole assemblages, and the ratio of the trial load to the absolute resistance.
5th. The cost; from which we shall draw
6th. Our conclusions.

1stly. *The absolute resistance of the materials; and the load they are exposed to on trial**.

The absolute resistance of bar iron, such by the way as is met with in commerce in France, is calculated to vary between 42,677 lbs. per inch superficial of the sectional area, to 56,903 lbs. The extreme limits to which the engineers of the Ponts et Chaussées test chains vary from 14,225 lbs. to 21,338 lbs. per inch superficial of the sectional area. The weight applied by the latest decisions of the superior administration is 17,073 lbs. per inch; or more than $\frac{1}{3}$rd of the mean absolute resistance, assumed to be equal to 46,945 lbs. per inch superficial.

The absolute resistance of iron wires of Nos. 17, 18, and 19 of the French gauge, or about from $\frac{1}{10}$ to $\frac{3}{32}$ inch in diameter, is equivalent to one varying from 85,354 lbs. to 113,806 lbs. per inch superficial, or about 102,427 lbs. on the average. The load to which it has been usual to expose them has ranged from 21,338 lbs. to 42,677 lbs. per inch; of late years it has been fixed at 25,610 lbs. per inch, that is to say, at only about $\frac{1}{4}$th of the absolute resistance of the iron. The reason why the wire chains are thus always constructed with such an abnormal excess of strength is entirely owing to the danger of the oxidation. It is with the view of providing for the diminution of strength attributable to this cause that the French engineers load the wire cables to so low a point when in place.

The absolute resistance of the hoop-iron cables is at least equal to that of iron in bars of a corresponding section; and may be considered at present as being 48,367 lbs. per inch superficial. The tension to which they were loaded at the time of the trial of the bridge of Suresnes was not allowed to exceed from 19,916 to 20,338 lbs.

To support the same load under these circumstances it would require the sections of cables of the different materials to be in the following ratios:—

Hoop-iron cables	5
Bar-iron „	6
Iron-wire „	4

2ndly. *The weight of the chains.*

In the bar-iron chains the supplementary weight arises from the joints, and resolves itself into the separate elements of the pins, the swellings out for the eyes, and the doubling of the iron in these parts. Their influence diminishes in proportion as the links of the chain are lengthened, and it is for this reason that the points of suspension in such bridges are kept as far apart as possible. When, however, these are spaced at too great intervals the chains become, in fact and in appearance, great polygons, producing a very disagreeable effect upon the eye, and have the additional disadvantage of being subject to deformations by any passing load.

The joints most closely arranged correspond with the axes of intermediate joists. They are rarely executed in this manner; some are spaced at the dis-

* The absolute resistances quoted in the text are such as are received in practice in France from experiments made upon the iron usually employed in commerce in that country. They differ a little from those we are in the habit of calculating upon in England; but as they are rather less than our own we may safely leave them as they appear in the text.

tance of three joists; but in general the joints are made to correspond with four, consequently requiring at least four separate chains on each side of the bridge. The supplementary weight may, therefore, vary from 25 to 60 per cent. of the weight of the chain itself; a fair average of some modern bridges gives a proportion of 30 per cent.

Comparing bar chains, weight for weight, with iron-wire cables, we find that the former, taking into account the joints, should be esteemed as being $1{\cdot}50 \times 1{\cdot}30 = 1{\cdot}95$, or nearly double the weight of the latter.

In the bridge of Suresnes the supplementary weight, consisting of the box joints, and the turning up of the hoops, was 264 per 1000 of the weight of the cable itself. The comparative weight with regard to a wire cable then became $1{\cdot}25 \times 1{\cdot}264 = 1{\cdot}58$, or rather more than half as much again. The joints of the iron-wire cables only consist of the wire woven round it from distance to distance, and are so insignificant that they may be neglected in the calculation.

Taking, in the comparison of the weights of the different modes of construction, that of iron-wire cables as unity, we find that the real weights of the different systems would be as follows:—

Wire chains, loaded with a weight of 25,610 lbs. per inch superficial of the sectional area	1·00
Hoop iron, loaded with 21,338 lbs. ditto	1·58
Bar-iron chains, loaded with 17,073 lbs. ditto . . .	1·95

3rdly. *The surfaces and volumes of the cables and chains.*

The surface of any body bears a greater relative proportion to its volume as its dimensions decrease. Thus a given weight of iron, say 2 cwt. of bars, hoops, or wires, employed in the suspension of a bridge, will have surfaces exposed to the action of rust, the more considerable in proportion as their diameter or their dimensions are smaller. The danger to be feared from the oxidation, and the quantity of painting required, will then depend on the surfaces exposed.

A careful examination of the dimensions of some of the most celebrated bridges, of the bridge of Suresnes, and of cables made of wires of different diameters, shows that, with a weight as above (say 2 cwt.), the surfaces exposed are relatively:—

For bar-iron chains	$1\frac{1}{10}$
For hoop-iron cables	8
For iron-wire „	40

in round numbers.

But it is to be observed that the exterior surfaces only of the hoop and wire cables receive three coats of paint; the interior surfaces are simply painted once. A greater scope is thus afforded to the action of the rust, nor does it seem possible to guard against it effectually. However, a comparison of the weights of the different systems, combined with the development of their external surfaces, shows that the ratios of the surfaces of painting are:—

For bar-iron chains	2
For hoop-iron cables	4
For iron-wire „	12

An inquiry of some interest was incidentally connected with this subject, respecting the proportion of the voids in a wire cable to the solids. The circular form of the elements necessarily prevents their juxtaposition, and the minimum of the void in any possible arrangement of the wires must naturally be that of the space inclosed between the three tangential circles. Now the space between three sectors is to the surface of the triangle which joins their centres as 1 to 1·1025. The minimum space then can never be less than 10 per cent. of the surface of the solids.

In forming a cable by the theoretical juxtaposition of its elements, the circles of the wires will group themselves as hexagons succeeding one another parallelly, and having a circle as their general centre. If from this centre a series of successive circumferences are drawn tangential to one of the circular elements of the surrounding series, it will of course surround a certain number of similar elements. The interior voids will always have the coefficient of 0·1025 already given; but it will be necessary also to add the exterior voids.

Determining, in this manner, the theoretical voids for a certain number of wires of the same dimension, it will be found that, for a cable composed of from 7 to 60 threads, the space will have a coefficient of 0·30.

When it is composed of from 60 to 120 the coefficient will be 0·25
„ „ „ 120 „ 320 „ 0·20
„ „ „ 350 „ 700 „ 0·185
„ „ „ 700 „ 900 „ 0·165

and from 900 to 1200 wires the coefficient becomes 0·155. It thus continues to decrease, and approaches more and more to the minimum coefficient of 0·1025.

Practically this juxtaposition can never be attained. The wires are always much twisted; they do not group themselves in a parallel manner, and the voids are always considerably in excess of those indicated by theory.

M. Leblanc, the engineer of the suspension bridge at La Roche Bernard, caused some cables to be made with particular care and attention. Sections were taken near the ligatures, and the coefficients were found to be, on the average, even with a great number of wires in the cables, between 0·42 and 0·45. The general average was nearer the latter, showing that the voids between the wires were 0·45 of the surface of the iron.

But, in the execution of large cables for the construction of a bridge, it is utterly impossible to attain the perfection which may be done with small experiments of the above nature. The wires cross one another, and when they are bound together in a strand, they are far from assuming the regularity of the above experiments. However well a cable may be constructed there necessarily remain large voids in the interior. Thus, at the bridge of La Roche Bernard there are two cables on each side of $6\frac{1}{16}$ in. diameter, composed of 1408 wires of rather less than $\frac{3}{8}$ of an inch diameter each; the ratio of the voids to the surface of the iron was 0·78 to 1. At the Fribourg Bridge there were also double cables on each side of the roadway of $5\frac{1}{2}$ inches diameter. Each cable contains 1056 wires, and the ratio of the voids to the solids was 0·96 to 1; and in the tieing-down bolts the ratio became as 1 to 1, or equality. It would appear from this that, practically, the voids are to the solids variably from 0·75 and 1·00 to 1.

The natural consequence of this fact is that a mass so divided is very much exposed to oxidation, because the air and the humidity enter freely, and act without opposition upon surfaces very considerable in proportion to the bulk.

4thly. *The absolute resistance of the whole assemblages, and the ratio of the trial load to the absolute resistance.*

The absolute resistance of an entire chain or cable, or of any description of assemblage, is inferior to that resulting from the resistance of its component parts. The causes of this attenuation differ in the cases of chains, or of iron-wire cables; it is not, therefore, advisable to fix the trial load with reference to the elementary resistance of the iron in either of them. It is necessary to take into account the manner in which the chain, or cable, is made, and the alterations which may be superinduced in the metal by it, and, at the same time, it is necessary to take into account the differences which may be caused by time or weather. The superior administration of the French Government engineers must, doubtlessly, have been influenced by these considerations when they adopted different trial loads for iron chain, or iron wire, suspension bridges.

It is to be observed that, by the term "trial load," it is meant that the dimensions to be given to the separate portions of the work are calculated upon the supposition that the greatest possible load which may be brought upon them shall not exceed those limits. Before the respective works are opened to public circulation they are all tested with dead weights in those proportions.

(1stly.) Iron-wire cables. The absolute resistance of iron wires is on the average 102,427 lbs. per inch superficial of the sectional area; the trial load has been fixed at 25,610 lbs. for that surface, or only 0·25 of the absolute resistance of the elements of the cables. It is, however, admitted by everybody, that such cables, shortly after their fabrication, can support a load of 29,874 lbs., or even of 38,410 lbs., without any perceptible fatigue. The bridge of Fribourg, amongst other instances, was proved to this extent, which was only 0·375 of the absolute resistance of the wires themselves. It is to be supposed, in face of this abnormal excess of strength, that the Government engineers consider that the wire loses in a very few years no less than $\frac{1}{3}$rd of its strength, not only from the action of the rust, but also from a chemical change, which may destroy the effect of the annealing the wires receive in passing through the rollers. If we suppose, then, that the real strength of the wires descends in the proportion above given to 68,293 lbs. per inch superficial, the coefficient of the trial load becomes 0·375, as at Fribourg.

But the absolute resistance of the wire cables is again very different from that of the wires of which they are composed, owing to the inequality of the tensions exercised. Experiments made by M. Leblanc upon strands composed of thirty wires, the total resistances of whose elements were from 25,610 to 27,032 lbs., showed that the mean coefficient of the strength of the united body was 0·832, or that such a strand would break with $\frac{5}{6}$ths of the load necessary to break its separate elements.

A cable is composed of a variable number of such strands, which also are unequally stretched, and therefore require the absolute resistance to be diminished by another coefficient. Indeed the spreading out of the strands upon the points of support, their preparation at different degrees of temperature, and a certain

inevitable degree of confusion and irregularity in the arrangement of the large cables ;—all these conditions operate to render the tension very unequal. It is probable that a second coefficient similar to the last, namely, 0·832, or the $\frac{5}{6}$ths, is necessary to arrive at the real absolute resistance of a cable composed of a great number of threads, thus giving a definite coefficient of 0·70 of the absolute strength of the elements. Thus we have for

A new cable $102{,}427 \times 0{\cdot}70 = 71{,}699$ lbs. per inch superficial absolute resistance.
An old ditto $68{,}293 \times 0{\cdot}70 = 47{,}805$ lbs. ,, ,,

Comparing now the trial load with the absolute resistances of the entire cables, we have

New cable $25.610 \div 71{,}699 = 0{\cdot}36$ nearly.
Old ditto $25{,}610 \div 47{,}805 = 0{\cdot}53$. ,,

The coefficient of 0·36, which is the actually existing one at the time of proving a bridge, because the cable is then quite new, is the measure of the perfect security of the system at that period. In fact no instance has ever occurred of the failure of a wire bridge during the proofs.

(2ndly.) Chains of bar iron. The resistance of iron bars varies from 42,677 lbs. to 56,903 lbs. per inch superficial; fibrous iron, such as should be chosen for the construction of the chains for bridges, has an average resistance of 46,945 lbs. per inch superficial. The trial load has been fixed at 17,073 lbs. per inch, or at 0·365 of the absolute resistance of the iron.

The absolute resistance of the chains is much less than that of the iron employed in their fabrication, because the welding, heating, and working it has to support alter its nature. Indeed the resistance of the chains often descends as low as the trial weight, and even below it, for they have often broken under its application.

Approximatively, however, it might be assumed that the absolute resistance of the chains is between 24,287 and 25,610 lbs. per inch superficial; although there is doubtlessly much danger to be feared from so high a limit, inasmuch as the chain, which might carry 26,610 lbs. for a short period, would break possibly if that load were left upon it for a great length of time. These indications are merely approximative, but they suffice to prove that the resistance of the chains is decidedly inferior to that of the iron bars themselves.

Some experiments made by Navier, at the factory of Guérigny, in the Nièvre, belonging to the French Government, in which all the large chain cables for the navy are made, confirm the above indications. The chains made there are proved with an hydraulic press to a point corresponding with a strain of 24,287 lbs. on the inch superficial, the chains being proved in lengths of 100 feet. Every link is carefully examined; and should the slightest fracture be manifest in any one, it is immediately removed. The chains are not received until they cease to exhibit such defects, and it is rarely that such is the case until after the third trial. This manner of fabrication and trial certainly offers every guarantee of perfection of execution; and we may safely assert that the suspension chains of a bridge, whose parts are proved separately, and for a few seconds only, cannot be considered as possessing greater powers of resistance, if they possess so great, as chains made and proved in this manner.

Now trials were made in the factory of Guérigny, for the purpose of ascertaining the absolute resistance of entire cables so prepared. It was found to be upon the average 35,564 lbs. per inch superficial. The coefficient then of the mean absolute resistance of the iron bars (which is 46,945 lbs.) is 0·76.

This would give the maximum resistance of a chain of a single set of bars; but in all large spans there are several sets of links placed side by side. Evidently their tensions are not the same, and the absolute resistance of the whole system must be again diminished in a similar manner, and, in order to keep within the limits of safety, in the same proportion as was previously done in noticing the effects of the strands of the wire cables. The coefficient of the resistance of a suspension composed of several chains may then be taken as 0·83 of that of the individual chains, thus making the resulting coefficient of the compound chain 0·581 of the bar iron itself. It is very doubtful, if of a hundred bridges executed, five could support a long-continued trial even within these limits. The safety trial load required by the superior administration of the Government engineers, namely, 17,073 lbs. per inch superficial, has, for its coefficient of the strength of the bars themselves, 0·365.

(3rdly.) Hoop-iron cables. The experiments made by Messrs. Flachat and Petiet showed that the mean resistance of the hoops was 48,367 lbs. per inch, and that the entire chains put together, of the dimensions and of the construction required in their definite positions, possessed an absolute resistance of 42,677 lbs. The coefficient of their power of resistance is then 0·88 of that of the elements which enter into their fabrication. The mode of trial was also as nearly as possible similar to the manner in which the real strain would affect the cables, nor could any subsequent inequality of tension arise from the positions of the chains in the bridge.

Grouping the results obtained from the above observations, according to the absolute strength of the iron, and of the chains, or cables, as we have examined them, we find the coefficient of the trial load to be, with reference to these latter, as under:—

Designations.	Mean resistance per inch sup.			Trial load, per inch superficial.	Coefficients.		
	Of the iron by itself.	Of the first assemblages, such as single chains or yarns.	Of entire chains.		Of the iron.	Of first assemblages.	Of the whole cables.
	lbs.	lbs.	lbs.	lbs.			
New iron wire . .	102,427	85,354	71,129	25,610	0·250	0·30	0·36
Do. at Fribourg . .	102,427	85,354	71,129	38,410	0·375	0·45	0·54
Old rusted wire . .	68,293	56,913	48,367	25,610	0·375	0·45	0·54
Bar iron	46,945	35,564	28,450	17,073	0·365	0·48	0·58
Hoop iron	48,367	42,677	42,677	21,388*	0·440	0·50	0·50

* Messrs. Flachat and Petiet consider that 21,388 lbs. per square inch would be a fairer safety load than 19,913 lbs., as fixed by the superior administration.

5thly. *The comparative costs of the different systems.*

It would be difficult to give any positive figures as to the cost of the different systems, because they must necessarily vary so much, according to the localities and to the care and pains taken in the execution of the work. We are, therefore, forced to confine our observations to general considerations connected with cost of execution.

In France, the prices of the different kinds of iron, as it is sold in the market, are usually as under:—

	£	s.	d.	Fr.	
Bar iron, per ton . .	20	0	0	or 50	per 100 kilogrammes,
Hoop iron	24	0	0	„ 60	„
Iron wire, No. 18 . .	36	0	0	„ 90	„

To compare the real cost we must, however, take into account the quantity of material of each description that would be employed to carry the same weight. We find, then, that the first cost of the material becomes:—

	Fr.			Fr.
Bar iron	50	×	1·97	= 96·50
Hoop iron	60	×	1·58	= 94·80
Iron wire	90	×	1·00	= 90·00

So that the cost of the material, in the first place, is nearly the same. The mode of fabrication, however, very soon changes the proportions of the cost. Thus, bar-iron chains involve a considerable outlay in their preparation, to which the cost of the coal and the waste in conversion must be added. The hoop-iron cables involve expense from the labour of putting them together, and for the machinery and tools required. The iron-wire cables are accompanied by expenses of the same nature. With all the different systems, also, it is necessary to take into account the cost of transport to the definite position, and that of the fixing. Under every circumstance of span, this is less for iron-wire cables than for any other system; although the comparative advantage increases with the width of the opening.

Taking into account, therefore, the prices of the different chains in place, the costs may be compared as follows:—

	Fr.		Fr.	
100 kilogs. of iron wire, at	1·40	the kilog.	= 140·0	or 1·00 ratio.
158 „ of hoop iron „	1·10	„	= 158·0	„ 1·236 „
197 „ of bar iron „	1·00	„	= 197·0	„ 1·41 „

Thus showing that the hoop-iron suspension cables, without being as cheap as the iron-wire cables, are considerably more so than the bar-iron chains*.

6thly. *Conclusions.*

The advantages of the hoop-iron cables appear, from the above examination of the different systems, to consist, in common with the iron wires, as compared with the bar iron;

* The preceding calculations of the cost of the different systems have been made upon weights and prices, such as are observed in France; but as the ratios which result from them would be the same if we had taken English terms of comparison, they may be allowed to remain as in the text.

1. In this, that they are formed of an assemblage of elements of smaller sectional dimensions, and whose resistance is consequently greater.

2. In employing the iron precisely as it leaves the rollers, in a state which allows its thorough and rigorous examination; it is not exposed to any re-heating, welding, or manipulation, which in all cases change the quality of iron.

3. In dispensing with the necessity of any preliminary proof of the iron, which, on the contrary, is indispensable with all kinds of bar chains. The least inconvenience arising from this cause is that, if the iron be proved to a strain equivalent to one of from 25,610 to 28,451 lbs. per inch superficial, it is sensibly fatigued; below those strains the proof would be useless.

4. In offering an element of security in the number of elements which enter into their composition, so that the defects of any one may be compensated for by the rest.

5. In submitting the iron to tensions sensibly equal throughout the cable, owing to the manner in which the hoop-iron cables are put together according to the form they are to occupy in place.

6. In being able to support a greater initial load.

7. In being lighter; not only because their strength is greater, but also because the supplementary weight of the joints is less. This is only $\frac{1}{8}$th of the weight of the hoop-iron cables, whilst it is $\frac{1}{3}$rd of the chains. The definite ratio of the weights is as 5 to $6\frac{1}{4}$.

8. In being cheaper, by about 15 per cent., owing to the diminution in the cost of the conversion.

9. In offering the same chances of durability, according to Messrs. Flachat and Petiet, although this is more than questionable. Those gentlemen consider the close approximation of the hoops to one another would prevent the air from entering between them, and that the oxidation in that case could not take place.

10. In being far more elegant in the curve they assume.

Comparing them, subsequently, with the iron-wire cables, the superiority of the hoop-iron ones may be considered as being, firstly, that they are not so liable to the destructive action of rust; secondly, that they form a compound body, all the members of which are exposed to equal tension; this cannot take place with the wire chains, as we have before seen. They partake, with the latter, of the advantage of being composed of numerous elements; and in the cost they approach more nearly to their economy.

The real superiority the hoop-iron cables possess over the iron-wire ones lies in their durability; the superiority they possess over bar-iron chains lies in their lightness, elegance, and economy.

We have, in the preceding notice of the bridge of Suresnes, followed as closely as possible the text of Messrs. Flachat and Petiet's descriptive notice, merely translating into English weights and measures such as occurred in their text. In our own country, where such immense strides have been made in the fabrication of bar iron directly from the roller, according to any pattern chosen by the engineer, one of the main objections, arising from the changes the iron is exposed to during the formation of the links, is so effectually obviated, that with us the application of hoop iron, introduced by those eminent

engineers, ceases to offer much interest. The practice of English engineers, however, has ceased to be confined to our own island; and the singularly varied circumstances under which they may be called upon to execute works in our numerous and wide-spread colonies may serve to explain our anxiety to introduce a manner of constructing suspension bridges which may be found to be the most economical under peculiar local conditions. It is, perhaps, an error incident to all scientific pursuits, that its followers are apt to seek theoretical perfection whilst incurring a sacrifice upon the first outlay. In colonies and new countries this error is more especially fraught with serious danger, and it is with the hope of being able to suggest means of constructing engineering works with economy that we have been induced to dwell at length on some, comparatively speaking, imperfect modes of construction. It is time enough to erect monuments for the admiration of posterity when a community has a superabundance of capital. In the commencement of any state, the first requisite for its successful development is the possession of easy modes of intercommunication, constructed with the least possible outlay.

We ourselves are far from coinciding in the opinions of the inventors of the system of hoop-iron cables as to the extent of its advantages. Yet many occasions may arise in which it would offer very considerable ones for the execution of works impossible under ordinary circumstances. It presents an additional resource, it gives additional means for the execution of works upon which, perhaps, interests of the greatest moment may depend. To us, then, it has a value far superior to that which may be due to its intrinsic and comparative merits. In engineering, still more than in legislation, does the philosopher's observation hold good, "That it is advisable to employ the best practical means rather than those which are theoretically perfect." Indeed, the cost of the means of developing national wealth should in no case be made to excuse a superfluous outlay of capital—such as has taken place to far too great an extent even in our own country.

During the execution of the bridge of Suresnes a modification of the original design was made by the introduction of a distinct curvature in the platforms of the separate bays, on each side of the central opening, instead of forming the whole bridge with one general curvature as is indicated by the drawing. The effect of the undulations of the floor line thus produced is extremely unpleasant to the eye, nor is the arrangement convenient for the purposes of carriage traffic. But it must have been necessary to give a distinct curvature to each bay, in consequence of the adoption of the principle of rendering every chain independent of the other members of the system of suspension.

At the present day this bridge appears to be in a very tolerable state, although it has supported an active and eminently fatiguing circulation during a period of nearly ten years. The hoops of the cables have detached themselves from one another in the intermediate spaces between the joints; so that, in fact, the suspensions are far from possessing the homogeneity of character claimed for them. But, inasmuch as the bridge has supported the continual passage of the troops going to and fro between Paris and the detached fort upon the Mont Valerian, one of the largest of the system of fortifications round Paris; and inasmuch as this proof has been continued during the whole of the

above-named period of ten years, it may fairly be considered to have supported every legitimate trial, and to offer very satisfactory results. During the passage of troops the unpleasant oscillatory movement which takes place in a direction perpendicular to the axis of the bridge in all cases where the suspension principle is applied, is very distinctly perceptible in the Suresnes Bridge. The only effectual remedy to this oscillatory movement appears to lie in the introduction of a system of cross bracing between the chains, such as was adopted in the Menai Bridge after the first serious injuries from the gales. In the case of the Suresnes Bridge the movement may possibly be the greater, inasmuch as the chains, or cables, are not confined laterally upon the top of the pier; but the real remedy, it must be repeated, would consist in the introduction of cross ties. These are the more necessary in such bridges as are executed with wire, or hoop-iron cables, inasmuch as the dead weight of the cables offers less resistance to any extraneous movement than chain suspensions would offer.

We may mention that the French military authorities, subsequently to the fall of the bridge over the Loire at Angers, have adopted the precaution of not allowing more than half a company of infantry to traverse any one bay of a suspension bridge at a time. The fact is, that when men have been accustomed to march in step, it is found to be impossible to prevent their relapsing into it if they move in large bodies. It is in vain to halt a regiment upon approaching a bridge, to order the men to break rank, and not to keep step whilst traversing it. Habit is too powerful; and, insensibly, soldiers fall into their regular pace. To guard effectually against the danger which arises from the uniformly repeated momentum of soldiers' tread upon suspension bridges, the authorities have ordered the passage of troops over such works shall only take place in small divisions—the first to have entirely cleared the portion between any series of points of support before the second is allowed to enter upon it. For instance, upon such a bridge as that of Suresnes three half companies might be upon it at one time, but no more.

A very remarkable defect exists in this bridge, namely, that the platform of the carriage way is not macadamized. The wood planking of the road thus left bare is necessarily destroyed with great rapidity; and the noise arising from the traffic is a source of inconvenience, nay, sometimes of danger, with restive horses.

Subjoined is a tabular statement of the principal dimensions of the Suresnes Bridge:—

Span of the catenary formed by the main cable . . .	203 ft. 3 in.
Do. do. do. side cable . . .	139 „ 5 „
Deflexion of main cables	20 „ 4 „
Do. of side cables	26 „ 0 „
Do. in parts of span of main cable considered as unity, about	0·10
Thickness of pier at level of platform	11 ft. 10 in.
Number of chains in each bay	2
Sectional area of hoops only, without reference to the size of the cable	10·8816 in.

No. XXVI. Hoop-Iron Suspension Bridge at Abainville. MM. Flachat and Petiet, Engineers.

This bridge, upon which MM. Flachat and Petiet made their first experiment upon the use of the wrought-iron hoops, is introduced for the purpose of showing the modifications they were led to make in carrying out their original conceptions, in consequence of the experience obtained by this first practical essay on a large scale.

The foot bridge of Abainville has a span of 134 feet 8 inches upon the chord line, with a deflexion of 10 feet 8 inches, or nearly $\frac{1}{13}$th of the span. The suspension bars are spaced about 3 feet $3\frac{1}{2}$ inches apart, and they are directly attached to the cast-iron boxes, which, at the same time, serve to receive the joints of the cable. There is a single cable on each side, composed of eleven hoops, whose united thickness in juxtaposition is 1 inch, and whose width is full $1\frac{1}{16}$ inch. The length of the hoops corresponds with eleven spaces, and is, consequently, 35 feet 3 inches. Each joint (of cast iron and of a single piece) receives the end of one hoop which commences, and of another which terminates; the hoops being disposed in such a manner as to cross the line of the axis of the cable at a very acute angle. The mode of fastening the ends consists simply in bending the iron round a small pin, and drawing the assemblage closely against the box. The cable is additionally fixed to the box joint by means of an elliptical wedge, driven through the middle of the cable, and traversing the joint by a hole in the centre left for its reception. The head of the suspension rod enters the lower part of the box joint, and is fastened to it by a small bolt with a key. The duty thus thrown upon the joint is to tie together the cable, and to carry the head of the suspension rods.

On reference to Illustration No. 25, it will be seen that the principal change introduced during the execution of the Suresnes Bridge was in the manner of executing the joints. The system adopted at Abainville was found not to produce a sufficiently energetic mode of binding together the separate elements of the cable. Nor, in fact, is this object attained by the more complicated joint introduced in the second example; for the hoops are, in many cases, detached from one another in a manner to produce very unequal tensions. In reality it is impossible to attain such perfection of execution as to bring into action the resisting powers of any system, whether of hoop or wire iron. Such methods must, therefore, after all, only be regarded as approximate solutions of the problem of obtaining an economical and homogeneous suspension chain.

Nos. XXVII. and XXVIII. Suspension Bridge over the Douro at Oporto.—M. Stanislas Bigot, Engineer.

Upon the principle we have advanced in the notice of the bridge over the Seine at Suresnes, of calling attention to economical methods of securing the great ends of the engineering art, by facilitating the methods of intercommu-

nication at the cheapest rate, we introduce a description of the iron-wire bridge over the Douro at Oporto.

La Villa do Gaya, the entrepôt of the wines of the Upper Douro, and through which the produce of Estremadura and Beira is forced also to pass, in former times only communicated with Porto by means of a bridge of boats. Frequently in the course of the year the river, swollen by the autumnal rains, or the melting of the snows, rendered it necessary to remove the bridge, which might otherwise have been carried away by the violence of the stream. The enormous expense of the annual maintenance and of the removal of the bridge of boats, the dangers it offered to the navigation of the Douro during the spring tides, combined with the risks attending the passage during the epochs of the withdrawal of the bridge during the floods, for it could then only take place in boats, induced the Government to propose the execution of a suspension bridge at the point where the old one had existed.

After long discussions, in which the municipal council of Porto proved themselves worthy brethren of the corporation of London, the design to be executed was definitively settled, as it is represented in our illustration. It consists of a single main span of 558 feet chord, supported upon four obelisks of about 59 feet high, tied together at the top by iron bars, spaced so as to receive the name of the queen and the date of the erection. These obelisks are founded upon rocks, which rise abruptly in the course of the river, and narrow its channel to such a degree as to give rise to a current which opposes the further advance of shipping. The main span is supported from four chains on each side of the roadway, upon which the saddles of the suspension rods are fixed, at distances of about 4 feet $10\frac{3}{4}$ inches from centre to centre. The intervals they leave upon the side of the bridge are filled in with a hand-rail and St. Andrew's crosses. The approaches were obliged to be kept in considerable elevation on the left-hand side, to allow of the free circulation under the platform of the bridge.

The anchorings of the chains on the side of La Villa Nova were executed in vertical wells, 49 feet 2 inches deep, including the loading mass carried up to the point where the cables are bent. From 16 feet 6 inches to 20 feet were excavated in the rock itself. On the side of Porto the anchorings are placed in wells sunk in the solid rock 27 feet below the cylinders, over which the cables change their direction. These cylinders themselves are on this side fastened to the rock itself; on the side of La Villa Nova they are attached to a body of masonry whose courses are disposed with reference to the resultants of the efforts of traction, and in thickness varying from 1 foot 4 inches to 1 foot 8 inches, the planes of the beds being normal to those directions. The inequalities of the rock on the Oporto side are compensated by masonry disposed according to the same principles.

The ground upon which the masonry was prepared consisted of a zone upon the immediate banks of the river, on each side; about 1300 feet long by from 4 to 20 feet wide, situated above the intended position of the bridge.

The yard in which the platform was prepared, the iron-wire chains woven, and the smiths' work executed, was situated about $\frac{5}{8}$ths of a mile on the down side of the bridge. The ground was levelled, and inclosed by a lofty palisade. The platform

was put together under its shade; the horses upon which the cables were formed were placed outside and parallel to it, in the sun; and lastly, between these horses and the provisional depôt of the great cables, a series of stands were prepared for the separate strands, and for drying the wires after covering them with the matters intended to preserve them from rust.

All the stone employed appears to have been of a granitic nature, easily worked, and of a specific gravity of from 2·25 to 2·30. The ashlar was brought in blocks, rough scabbled, of from 17 feet 6 inches to 21 feet cube each. The mortar was obtained from the environs of Ovar, and was perfectly hydraulic; the sand was derived from the bed of the river, and consisted of a detritus of quartzose granite of a sharp grain, and very pure. Owing to the different velocities of the river within very narrow limits, it was easy to select the sand of the degree of coarseness or fineness the work required. The common mortar was composed of one measure of lime, reduced to a pasty consistency, to one of sand. The ashlar was set in a species of cement formed of one portion of pounded tiles to two portions of slacked lime in paste, and two of sand. The concrete was composed of two parts of ordinary mortar to three parts of ballast, or broken granite, from 2 to 4 inches cube. These different combinations of mortar were arranged from previous essays, and they were found to have become perfectly hard after two months' submersion in the water.

The heavy castings of the cylinders upon which the change of direction of the cables takes place, were executed in England. The heavy iron work for the junction of the cables was executed in wrought iron from France; the material required for the details of the wood-work, and the common iron-work, was entirely of Swedish iron. The wires were manufautured at Besançon, in France; and those which appeared the most defective were proved to twice the weight they were intended to bear in their definite positions.

The wood employed for the frame-work of the bridge, and the first course of planking of the roadway, was of Baltic or Swedish fir, cut square. The upright posts, and the braces which carry the hand-rail, with the hand-rail itself, were of Prussian oak. The second course of planking of the roadway was of poplar, from the neighbourhood, as was also the wood used for the scaffolding. The wood of the immediate neighbourhood was soft and at the same time heavy; its strength was little, and its durability also very insignificant; nor was it possible to procure trees of any size. It was for these reasons that the fir from the north of Europe was adopted; the wood principally came from Stockholm.

The wires for making the cables were of No. 18, of the French wire gauge, or 0·124984 of an inch diameter. The furnisher had guaranteed its actual resistance to be at least equal to an effort of traction of half a ton, or about 78,120 lbs. per inch superficial (a very modest limit, by the way, according to M. Flachat's experiments); some of them were proved up to 93,720 lbs. without exhibiting any signs of failure. It was found, however, on examining the bundles of wire, that they were very badly manufactured, and many of the wires had to be entirely rejected. The wire for forming the sheathing of the ropes was of No. 14, and that for tieing the joints of the wires was of No. 4; both were carefully tempered, or annealed, before being used.

In the commencement, the wires were covered with a mixture composed of

linseed oil, in which litharge, white lead, and lamp black were dissolved. This mixture was not found to give satisfactory results; and, after several other essays, the system recommended by M. Bonnet was adopted, which consisted in immersing the wire in coal tar liquefied at a feeble heat. The coal tar was procured in Oporto; and it was found that in a boiler 2 feet 8 inches long by 2 feet 8 inches high, 4 tons of wire could be prepared in a day. A single immersion in this fluid is asserted to protect it against the influence of rust for several years. The wires, after having been dipped in the coal tar, were suspended in the open air to dry, and, although copious rains fell upon them, no trace of oxidation could be observed. A certain amount of care is requisite in the use of the coal tar, for its drying takes place slowly, and it begins to coagulate at about 50° Fahrenheit. Wires which had been joined in the early part of the morning, when the temperature was about 50°, and had then resisted a strain of from 6 to 8 cwt., were torn asunder at mid-day, when the thermometer reached from 70° to 76°, with a weight not exceeding from 4 to 6 cwt. To obviate any danger from this cause the portions of the wires to be joined were carefully cleaned, and, when the joint was made, they were coated with the coal tar.

This bridge was proved before being opened for public circulation by laying a dead weight equal to 24½ lbs. on a square foot of the area. The French engineers of the superior administration are more particular and more exacting than those of Portugal appear to have been, for the load they require in such cases is 44·1 lbs. per foot superficial. With the load actually applied the centre of the bridge was only brought down six inches, which it recovered again upon its being removed, after it had been allowed to remain on for about 24 hours.

If, however, we apply M. Flachat's results to the details of this bridge, it may be questioned whether the main chains are sufficiently strong, particularly as our recent experience confirms, and even exceeds, the allowance proposed by that engineer to compensate for the deterioration of the iron wire. For, if we assume the bridge itself to have weighed 557·52 lbs. per foot forward, which is undoubtedly rather below the real weight, and the proper load to which it ought to have been exposed in addition to have been 890·82 lbs. per foot forward, the tension upon the main cables would have been as follows, from the formula,

$$T = \frac{p\,h}{2f}\sqrt{h^2 + 4f^2} = 1{,}304{,}834 \text{ lbs.};$$

in which p = the weight of a foot linear of the bridge = 1448·34 lbs.,

h = the half chord = 279·1 feet,

f = the versed sine = 45·21 feet.

Now, if we assume that the absolute resistance of an old iron-wire rope is, as M. Flachat states, only 48,805 lbs. per inch superficial of its sectional area, the absolute resistance of the cables of the Douro Bridge would not exceed 48,805 × 50 = 2,440,250 lbs. after a few years. The cables ought, according to this calculation, to have been increased 0·60 per cent. to ensure a permanent excess of three times the resistance to the effect of the load, or about 0·08 per cent. to secure the more reasonable excess of double the ultimate resistance. Probably the climate of Portugal may be more favourable than the more northerly climates of England and France to the duration of the wires; for we actually find that this bridge bore the passage of numerous bodies of troops

during the civil wars of 1847, five years after its completion, and it is universally acknowledged that no test can be so severe as the one a suspension bridge is exposed to by such passage.

The cost of this bridge is said not to have exceeded 20,000*l.*, or about 36*l.* per foot forward of the clear span, or 1*l.* 15*s.* 6*d.* per foot superficial of the roadway. The economy of this mode of constructing suspension bridges must then be apparent; and in the imperfect state of development of the resources of countries less far advanced in civilization than our own, it is not surprising that they should be so frequently employed. National civilization at the present day is measured by the concentration of capital; where this does not exist forcedly, the more imperfect methods of establishing intercommunication must be resorted to. This law will hold good in our own colonies, and in our East Indian possessions; and it is, therefore, much to be regretted that our engineers have so strong a prejudice against the use of the cheaply-executed iron-wire bridges. The fall of some of the French wire bridges has lately confirmed this prejudice; but a careful examination would rather lead us to believe that they fell, not so much from the defects of the cables, as from other faults of the constructions.

The span, or chord line of the cables, was, as before observed, $558\frac{2}{10}$ feet with a versed sine of $45\frac{2}{100}$ feet. There were eight cables in all, four on each side of the roadway, consisting each of 400 wires of No. 18 gauge. The anchoring, or tieing-down cables, double in number, were each composed of 220 wires of the same gauge; the suspension cables of the platforms were composed of 36 wires, also of No. 18.

The roadway consisted of a carriage road 13 feet 6 inches wide, and two footpaths, 3 feet 4 inches wide each. It was supported upon fir joists 1 foot 1 inch deep in the centre, reduced to $10\frac{1}{2}$ inches at the ends, by $10\frac{1}{2}$ inches wide; they were alternately 25 feet and 33 feet long. From the longer joists struts were carried up to support the hand-rail. The longitudinal section on the axis of the bridge was laid with a curve of 4375 yards radius, and the shortest suspension rod was 8 feet 4 inches long. Upon the top of the joists a longitudinal baulk, 1 foot high and $9\frac{1}{4}$ inches wide, was fastened at each side of the carriage way; similar baulks were also placed at the outsides of the footpaths forming the bottom cills of the hand-railing. Courses of timber, $7\frac{1}{4}$ inches wide and $5\frac{1}{2}$ inches thick, are fastened to these upper longitudinal baulks, by means of bolts and stirrups connecting them at the same time with the transverse joists. The floor of the roadway is formed by a first layer of fir planks, 4 inches thick, laid longitudinally. They do not touch laterally, but a space of about $\frac{1}{2}$ an inch is left between each plank, to allow of the circulation of air between them. A second layer of planking, of poplar, furnished by the country, 2 inches thick, and in boards from 7 inches to 10 inches wide, is nailed upon the top of this longitudinal planking, and transversely to it. The joists are kept square under the footpaths of the dimensions above given; under the roadway, they are reduced according to a segment of a circle, with $2\frac{1}{2}$ inches rise to throw off the water. A space $1\frac{1}{2}$ inch wide is left to allow the water to escape.

The hand-rail is formed with upright posts, 4 inches wide by $2\frac{1}{2}$ inches thick, and raking braces in the St. Andrew's crosses, 2 inches square at the ends by $3\frac{1}{4}$

inches square in the middle. The consoles, which are carried out in the form of the letter S upon the alternate joists, are of iron, $1\frac{1}{2}$ inch $\times$ $\frac{1}{4}$ inch, screwed to the joists and hand-rails.

The footpaths are floored with fir planks, 2 inches thick, nailed to the longitudinal baulks. They are protected from the roadway by small squares in wrought iron, $1\frac{1}{2}$ inch square, placed from distance to distance, and by a species of "borne," 8 inches high and 3 inches wide, beyond the open space between the longitudinal baulk and the planking of the roadway. The whole of the timbers of the roadway were carefully covered with hot vegetable tar upon all their faces before being fixed.

In order to facilitate comparisons with similar works of this kind, we subjoin the principal dimensions of this bridge in a tabular form.

Span of the catenary formed by the cable	558 ft. $2\frac{1}{2}$ in.
Deflexion of do. do. do.	45 „ $2\frac{1}{2}$ „
Do. in parts of the span considered as unity	0·081
Breadth of the platform of the bridge	20 ft. 2 in.
Thickness of the pier at level of platform	10 „ 0 „
Number of chains, or cables	8
Sectional area in centre of bridge, of the wires alone, without reference to the size of the cable . . .	49·9872 sup. in.
Date of completion	1842.

Nos. XXIX. and XXX. Plan, Elevation, and Details of the Balloch Moyle Viaduct, on the Glasgow and South Western Railway. J. Millar, Esq., Engineer.

We are compelled to omit the observations we had intended to make upon this very beautiful viaduct, in consequence of our receiving a letter from Mr. Millar stating that, although he had previously promised to give us the detailed notices requisite to enable us to examine its construction thoroughly, he had decided to communicate all the information he possessed upon it to a party engaged in preparing a work in which several of the structures executed under his orders are to appear. Our engraving was finished, and the printing begun, before we received Mr. Millar's letter, or we would not have *appeared* even to interfere with his wishes. As it is, we confine our remarks to calling attention to the boldness and elegance of the proportions of the viaduct; and, at the same time, to observe that, although this work has eminently succeeded, the lightening of the piers, and the spandril of the great arch, was carried to a hazardous extent. The bulk of railway contractors build so badly that great danger is attached to the pushing economy to its utmost limits. Doubtlessly, Mr. Millar will publish the calculations upon the stability of the great arch which led him to execute it with the lightness which characterises it. The hollow piers of the smaller arches we have already seen, in the cases of the Malaunay and Barentin Viaducts, to be attended with a risk hardly to be encountered for the sake of the trifling saving they can possibly procure.

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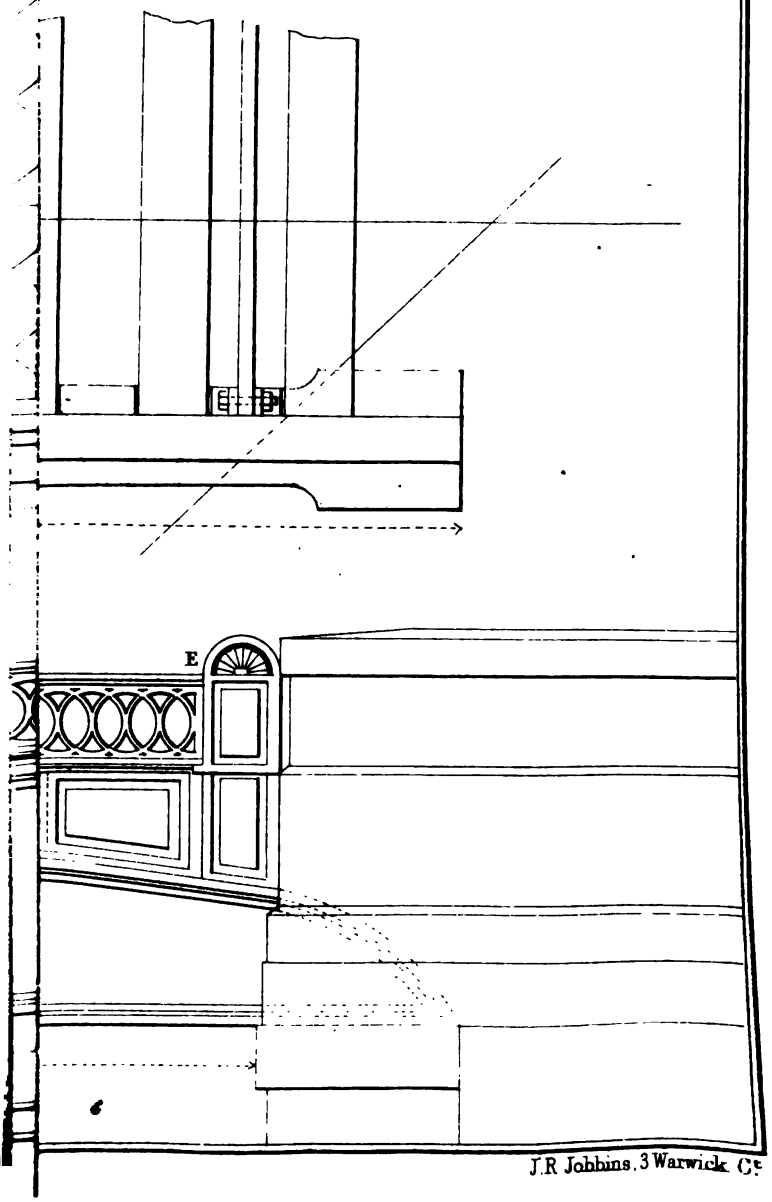

J.R Jobbins, 3 Warwick Ct

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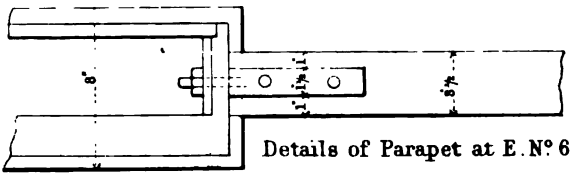

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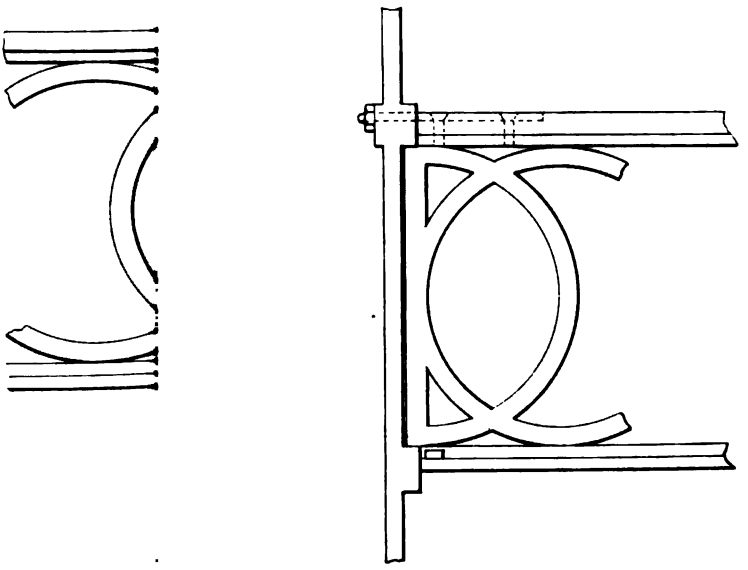

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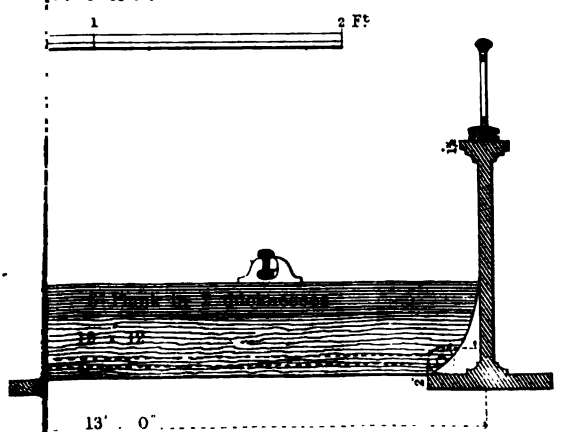

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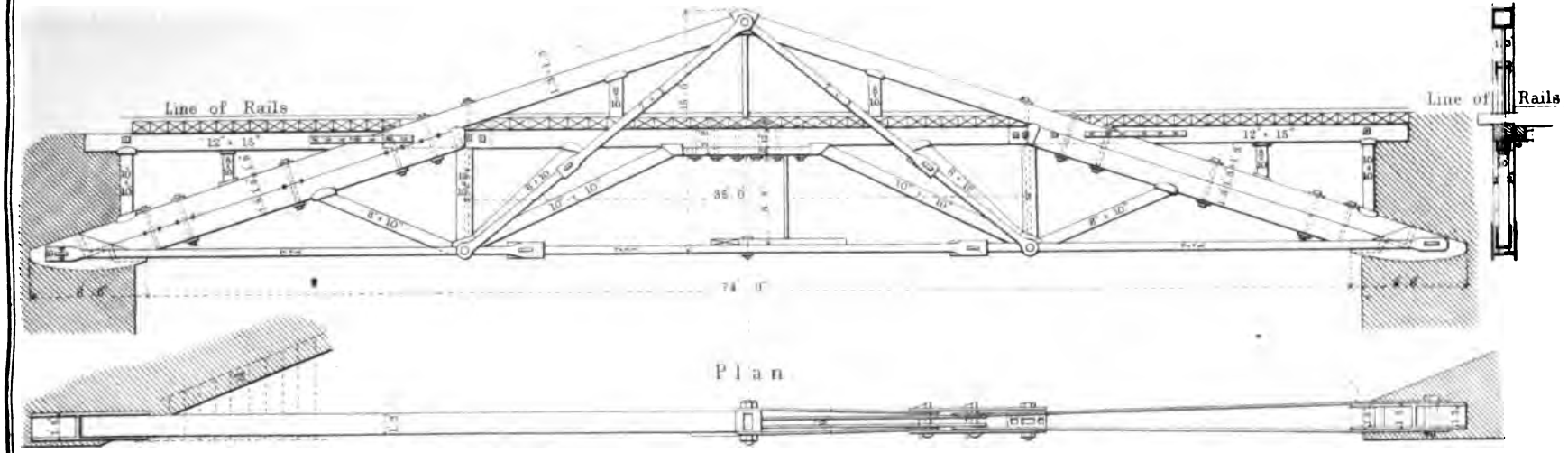
CHELTENHAM & G.W. UNION RAILWAY.

St MARY'S VIADUCT.

Elevation of Truss.



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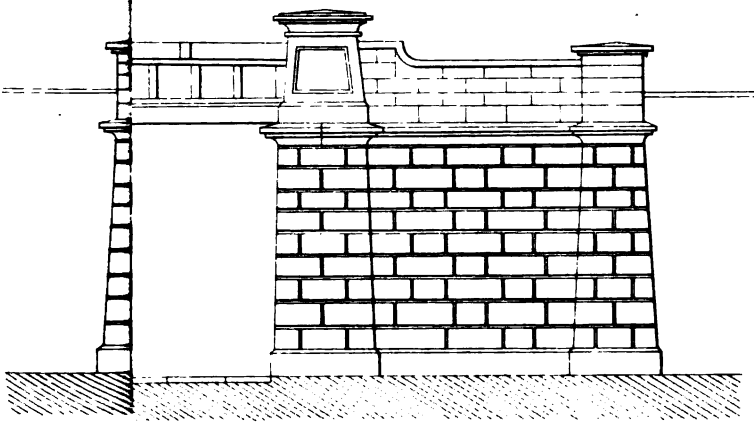

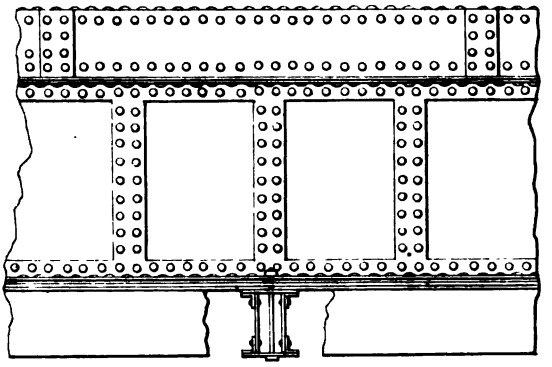

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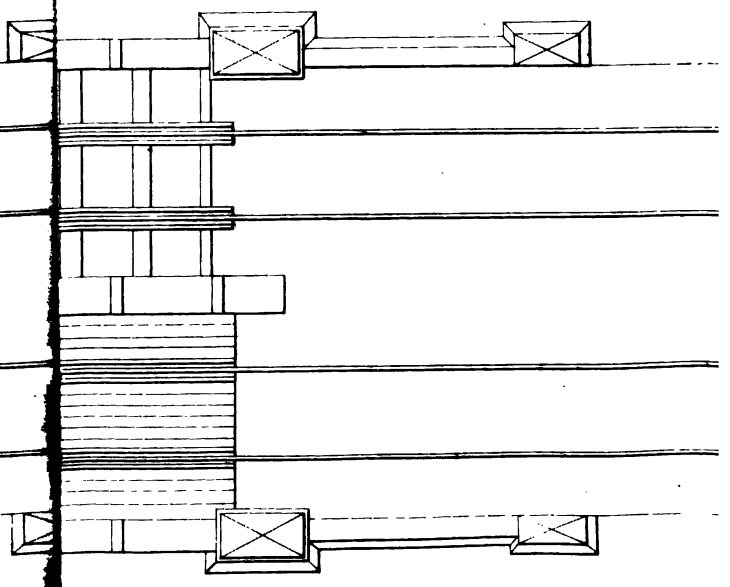
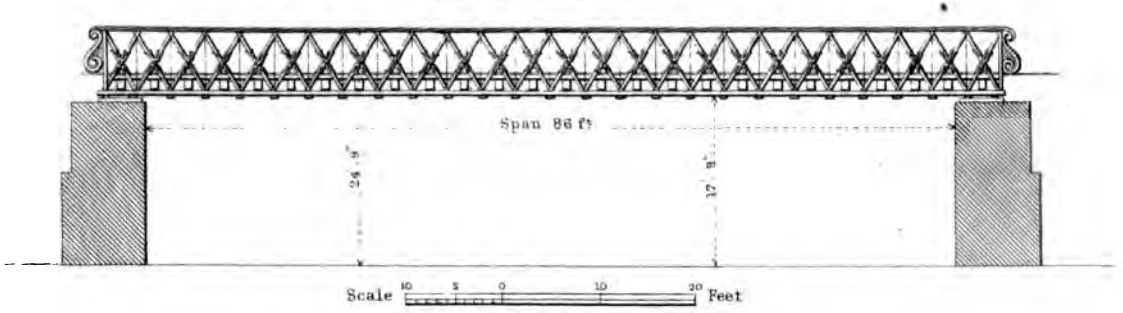
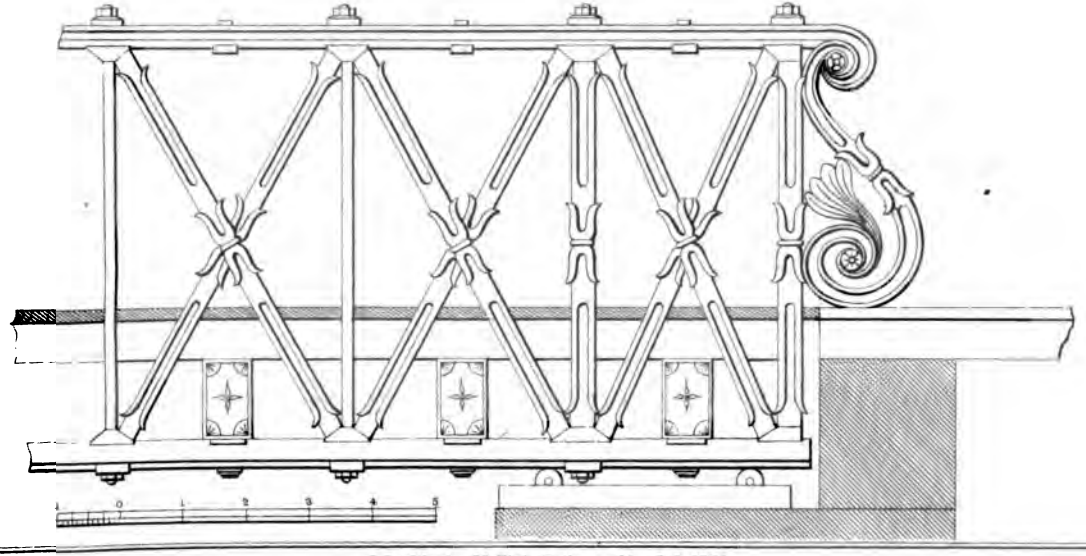
Enlarged Elevation of Outside Plates.



WATERFORD & LIMERICK RAILWAY.

BALLYSIMON BRIDGE.





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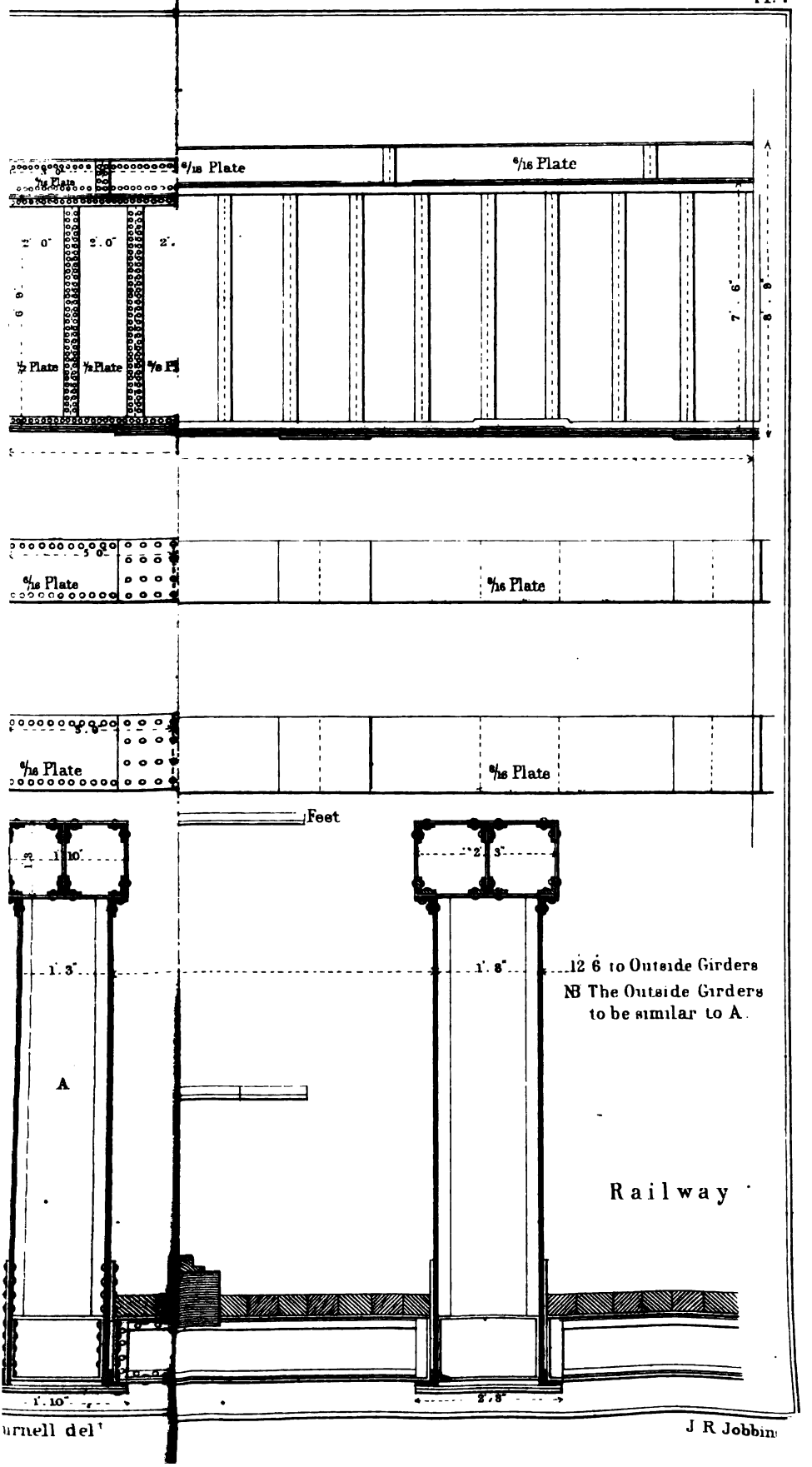
J.R.Jobbins



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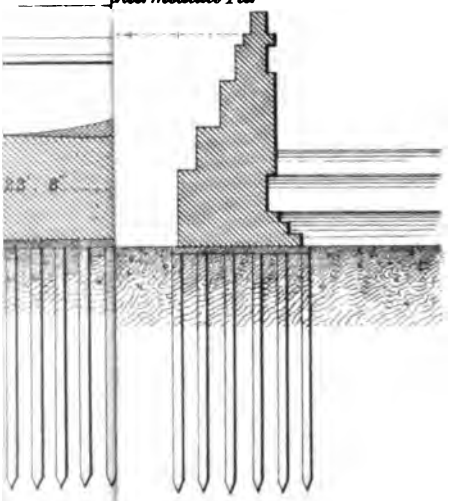

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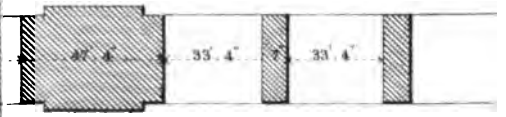

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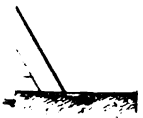
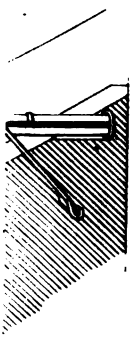
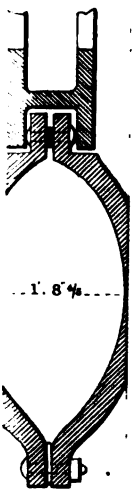
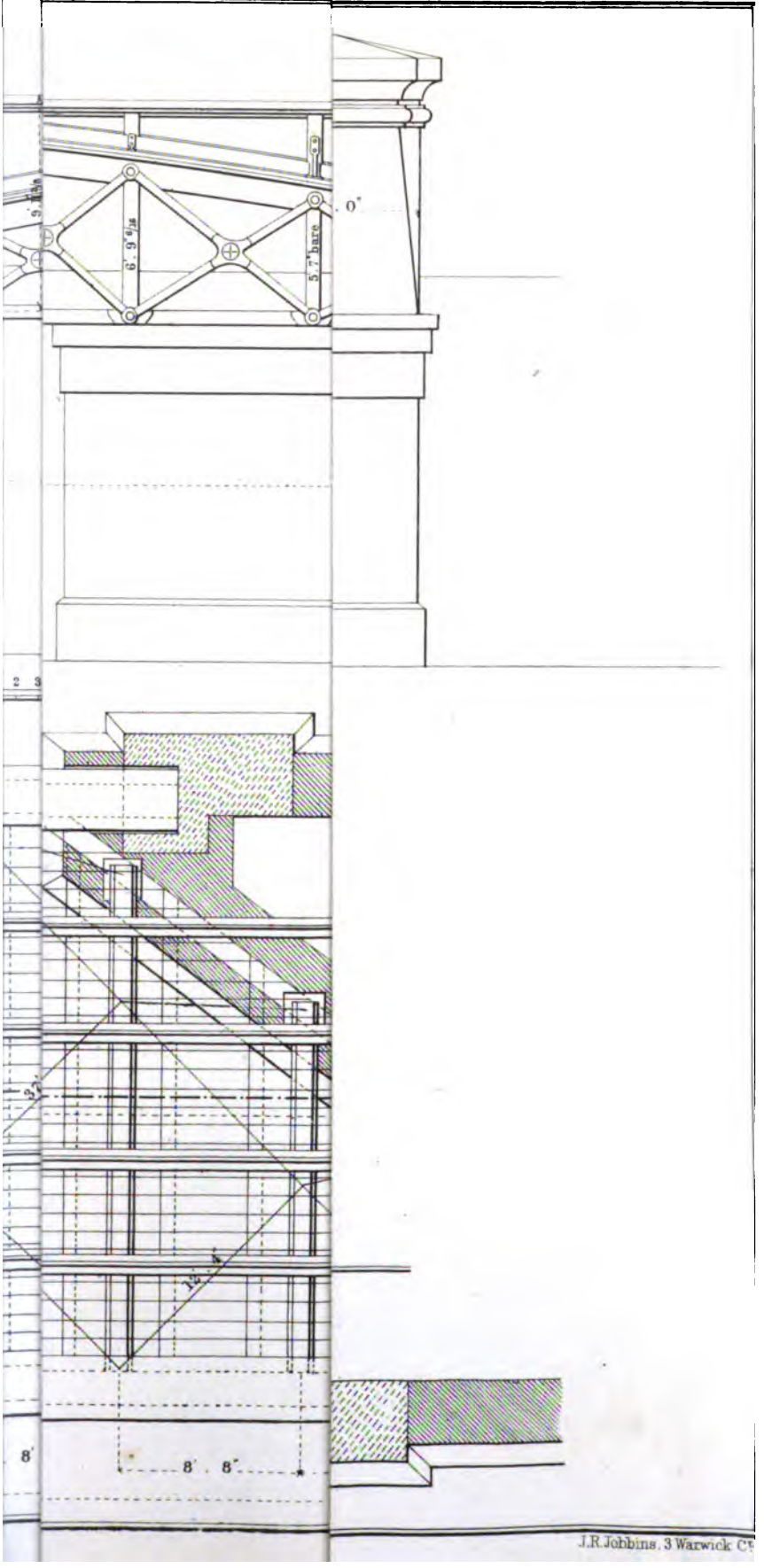
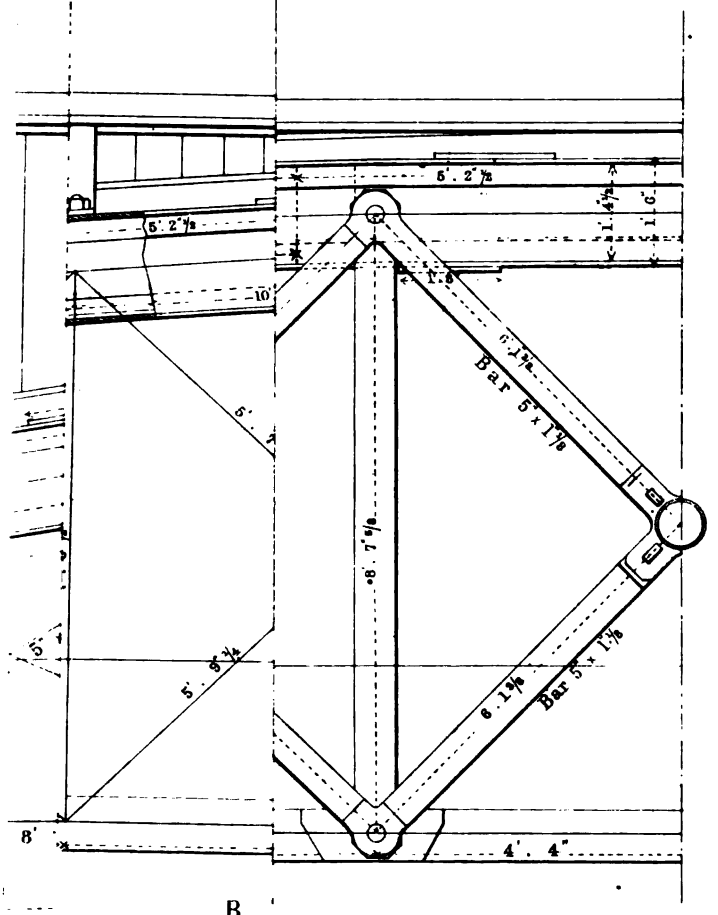








J.R.Jobbins, 3 Warwick Cr



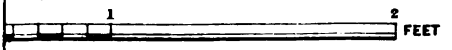
B.

EXTENSION RAILWAY,

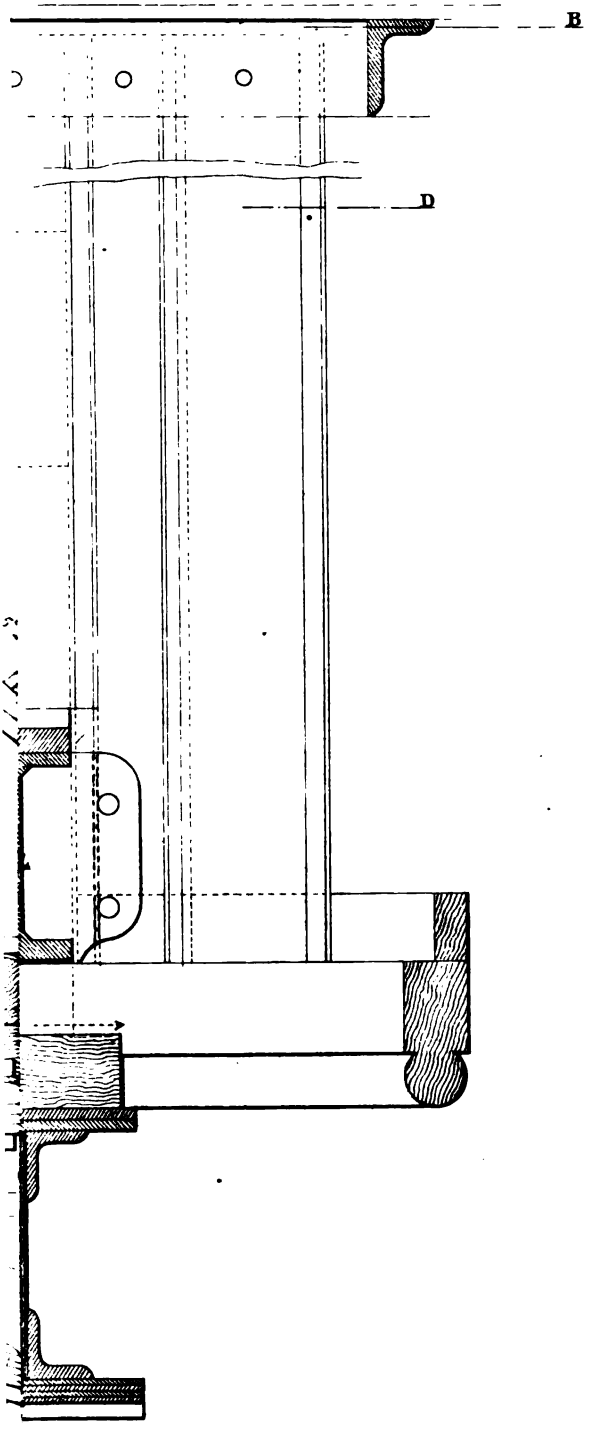
CIAL ROAD BRIDGE.

Fig^{s} A. or ⅜ inch = 1 Foot.

Fig^{s} B. or 1½ inch = 1 Foot.



J.R. Jobbins



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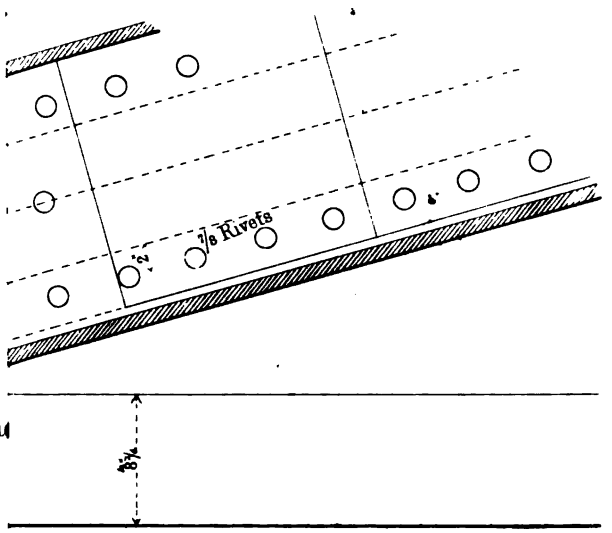
ls 1½ = 1 Foot.

1 2 FEET

J.R Jobbins, 3 Warwick Ct



pansion Shoe. (¾" on each side)

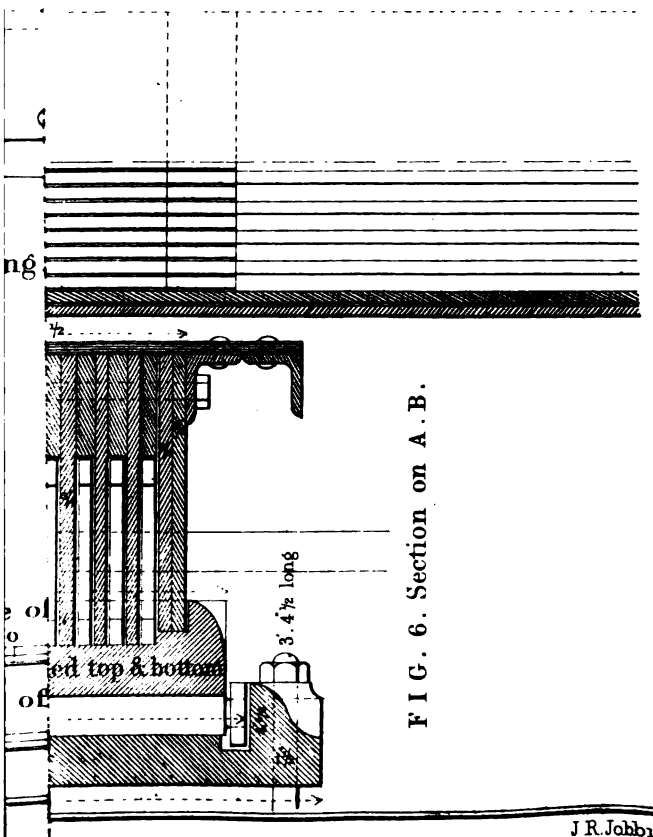
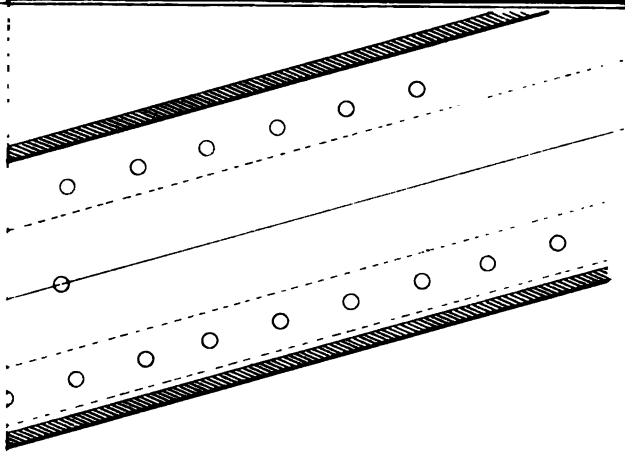


FIG. 6. Section on A.B.

J R Jobbins



. thro' A . B.

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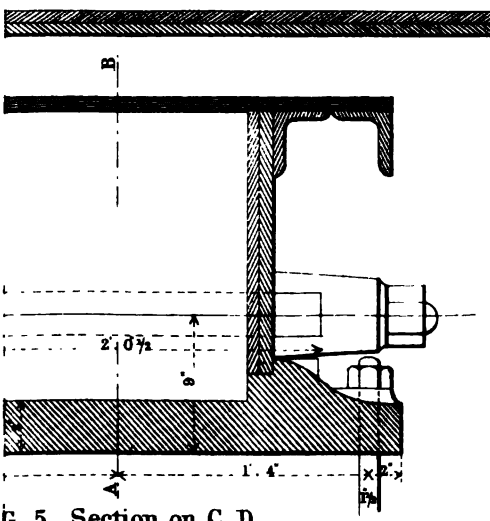
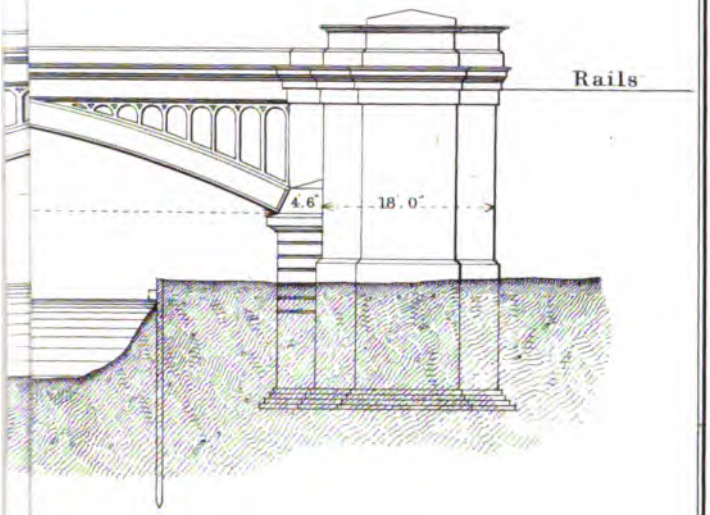
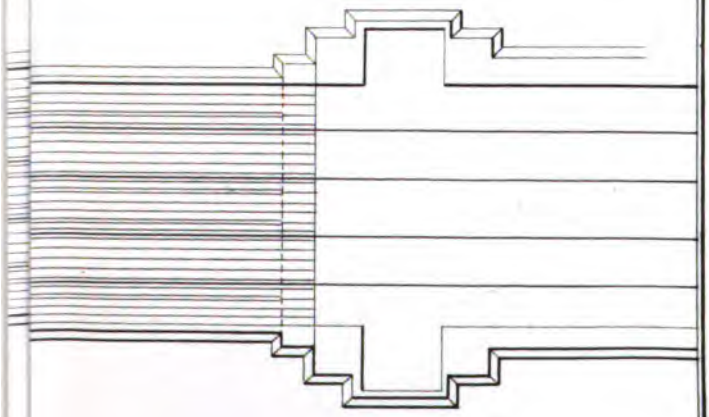


G. 5 . Section on C.D.





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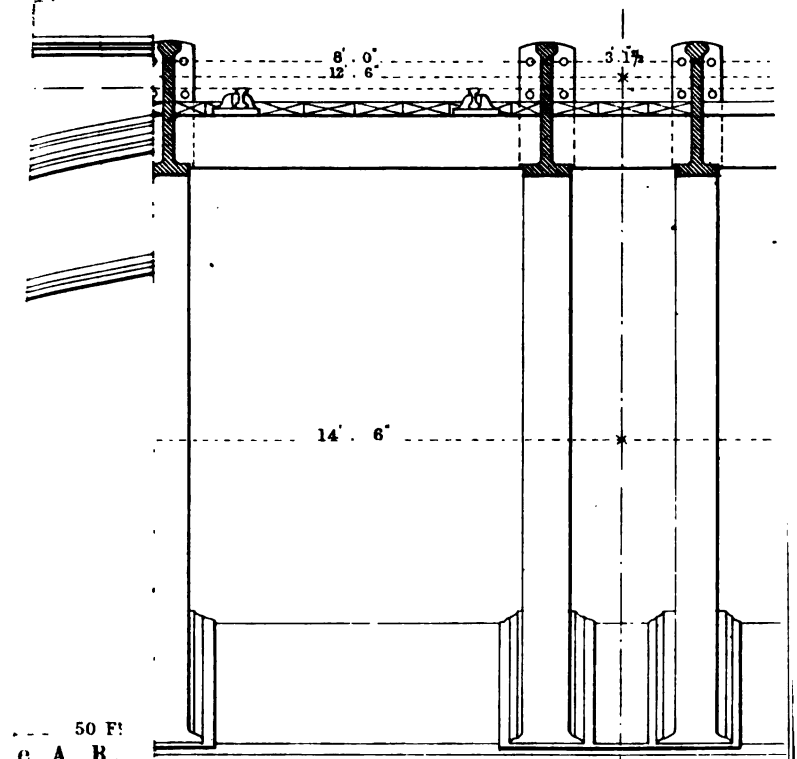
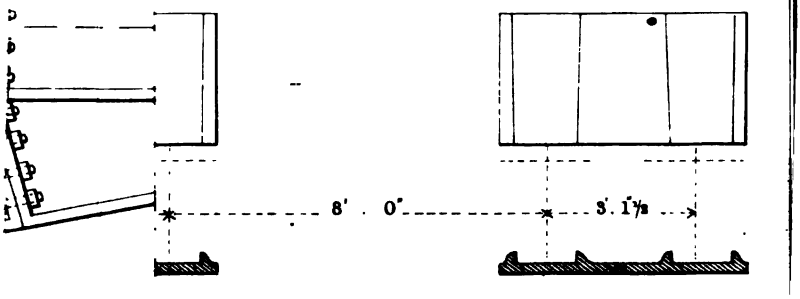
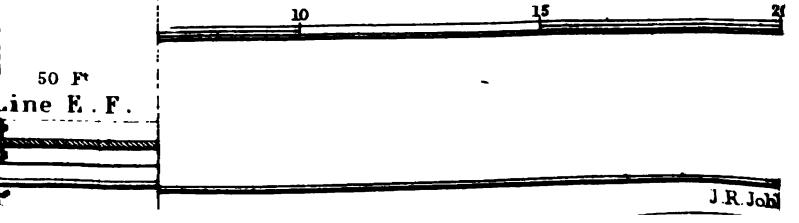


Transverse Section.



Details of Springing Plate.



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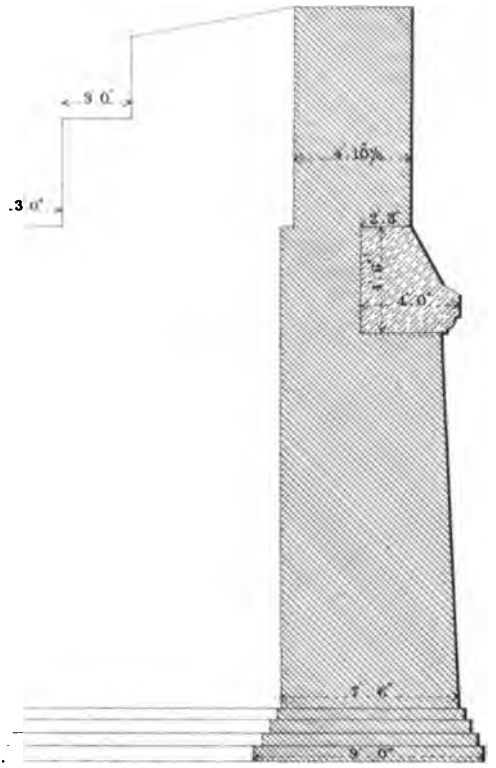
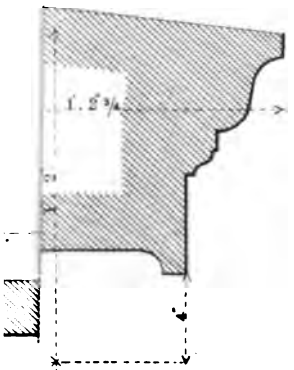
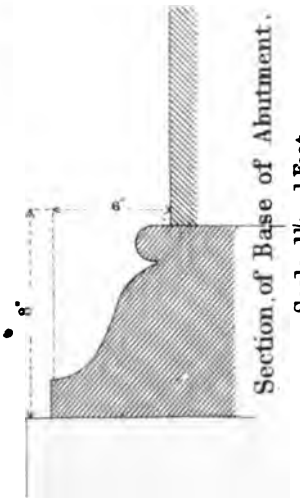
Section of Abutment.







Section of Base of Abutment.

Scale 1½ = 1 Foot.

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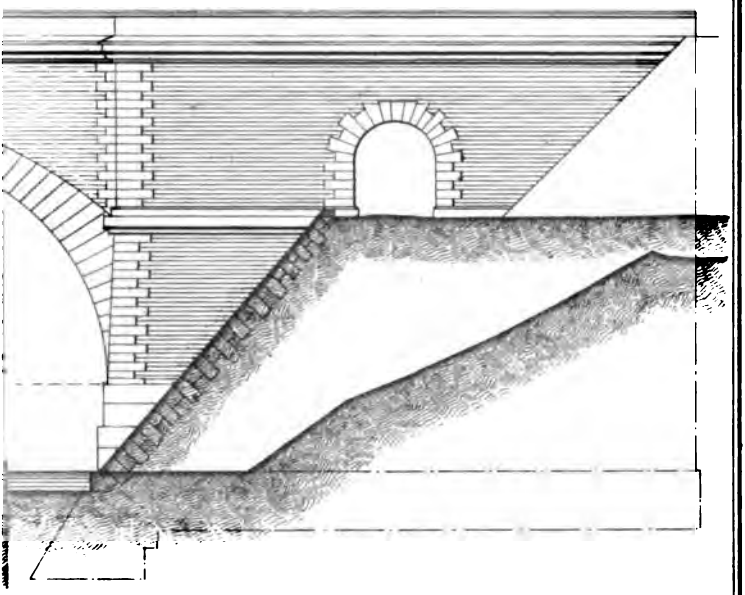

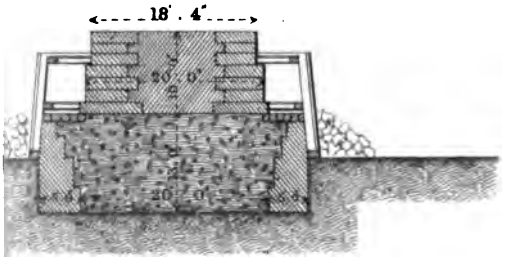

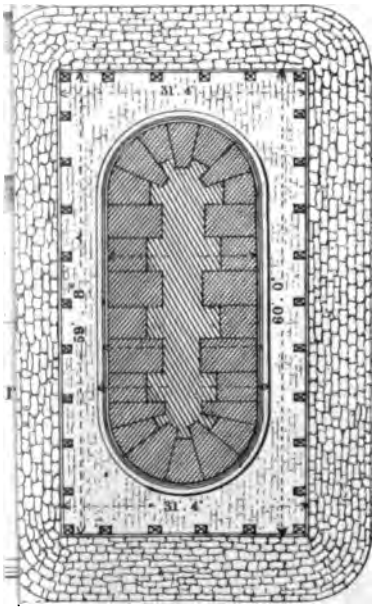

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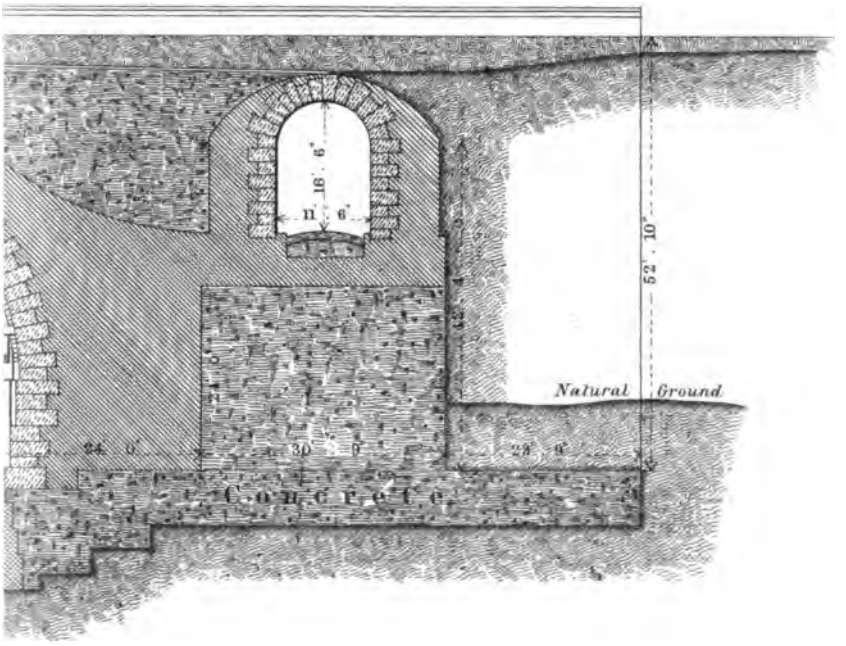

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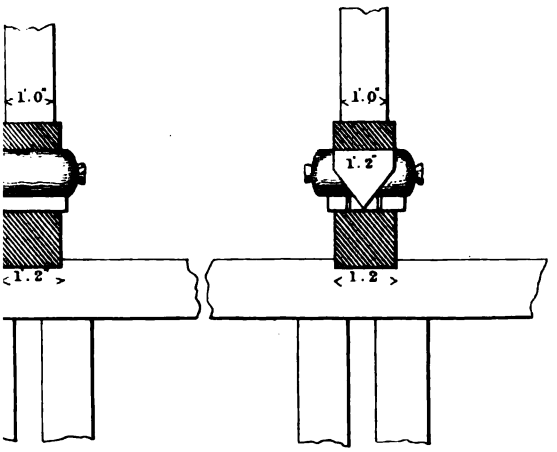

on A . B.

Section on C . D.

After first cut in the Cills.

Scale of Details.

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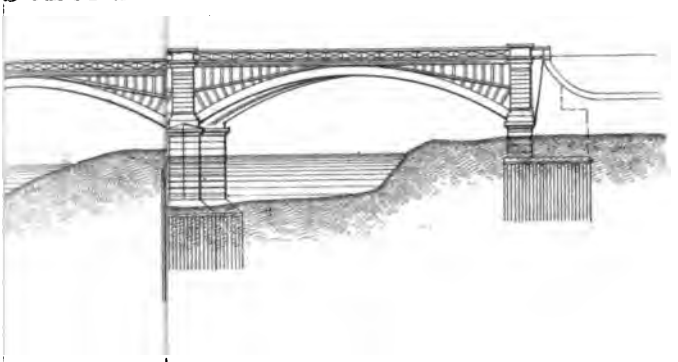

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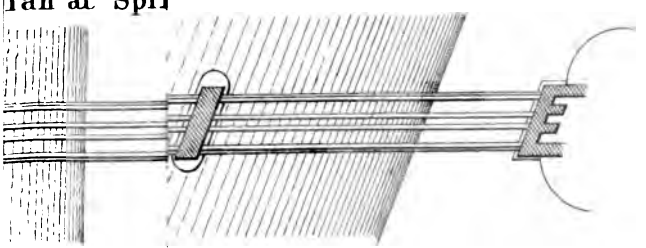

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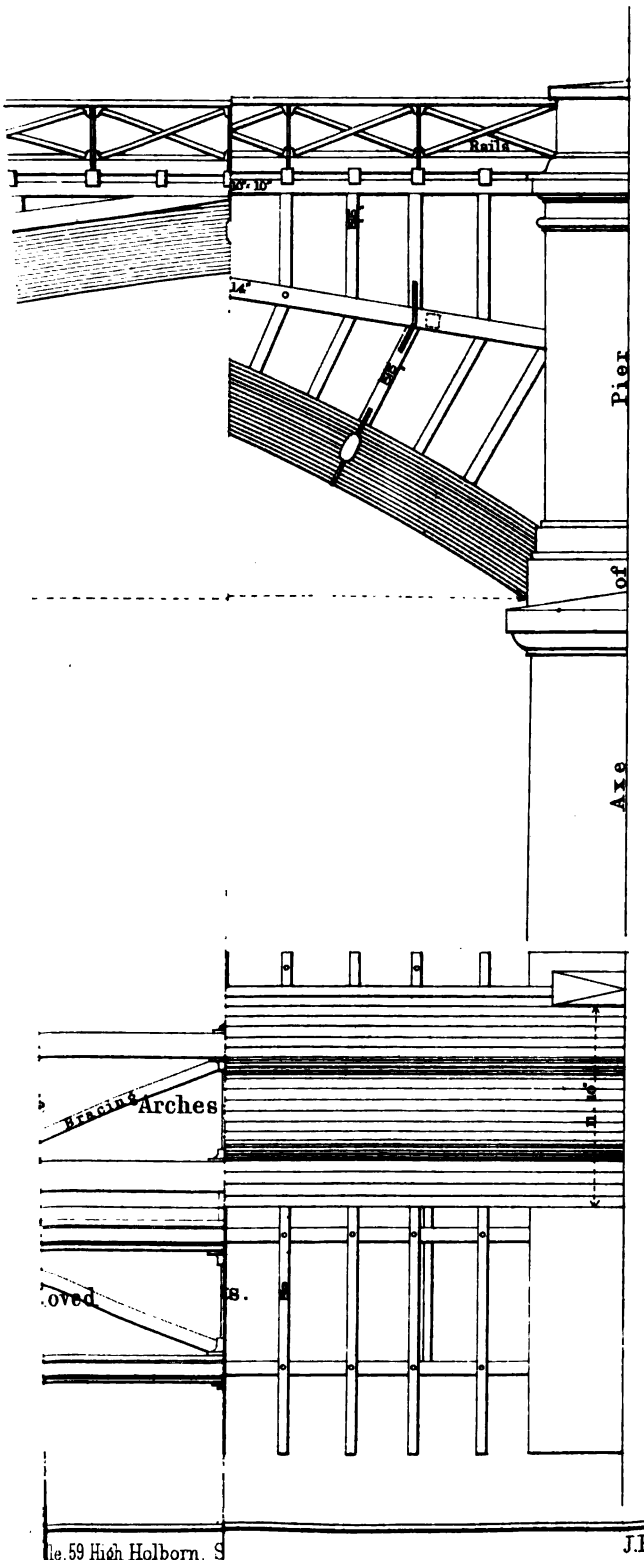

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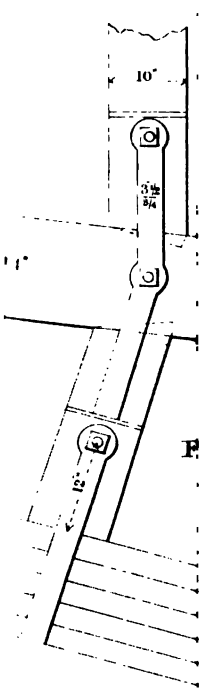

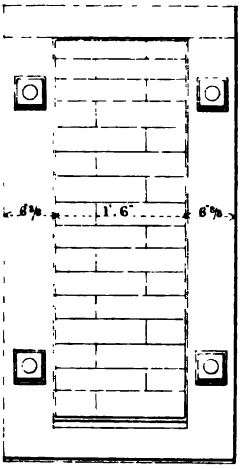

FIG. 9.

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FIG. 8 to 13.

tails of Cast Iron Shoe of Arches.

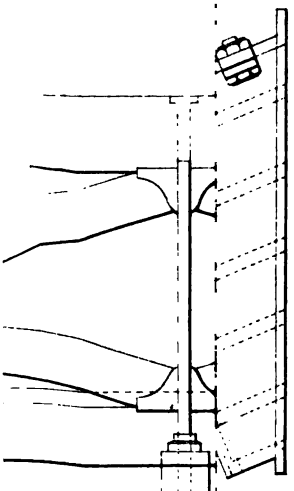


FIG. 10.

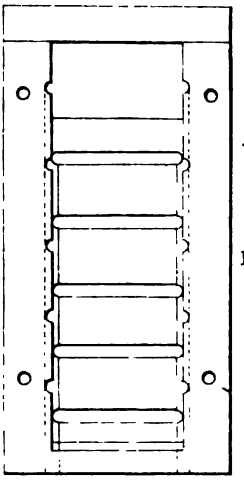
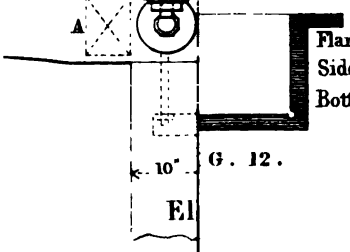


FIG. 11.



G. 12.

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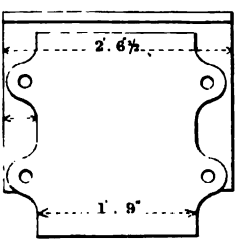

FIG. 13.

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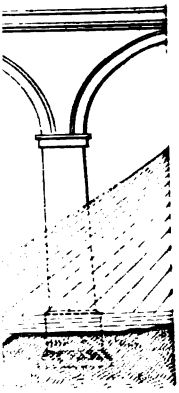

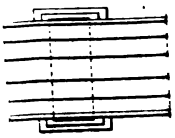

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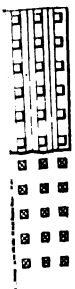

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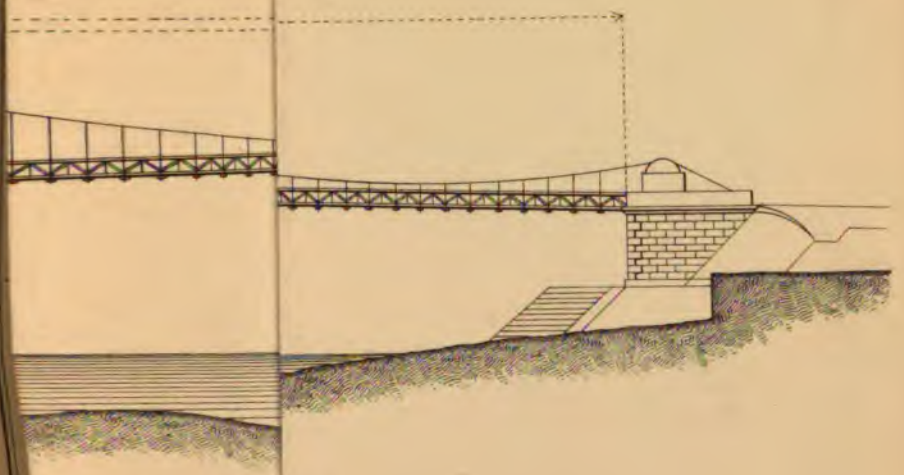
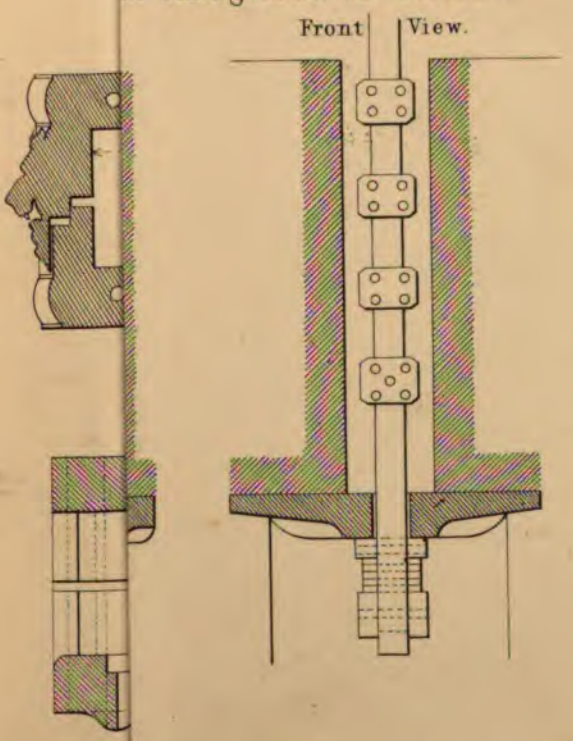
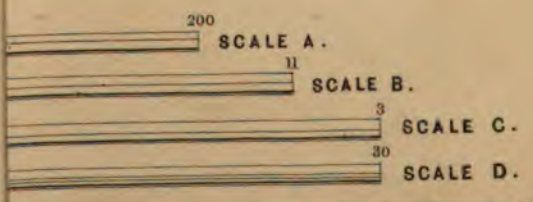


of fixing ends of Cables.





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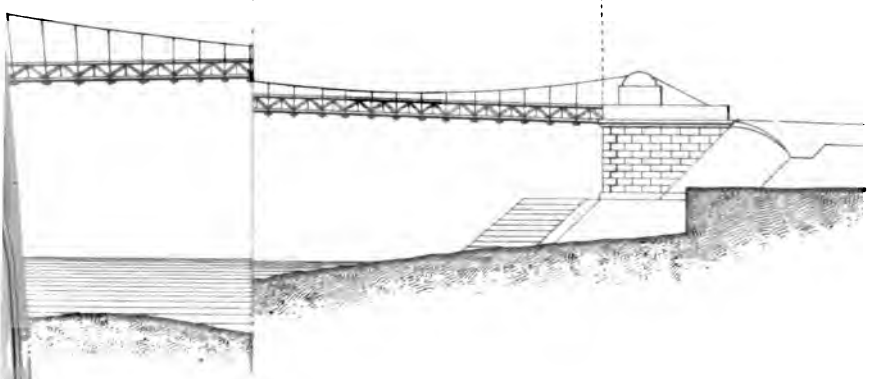
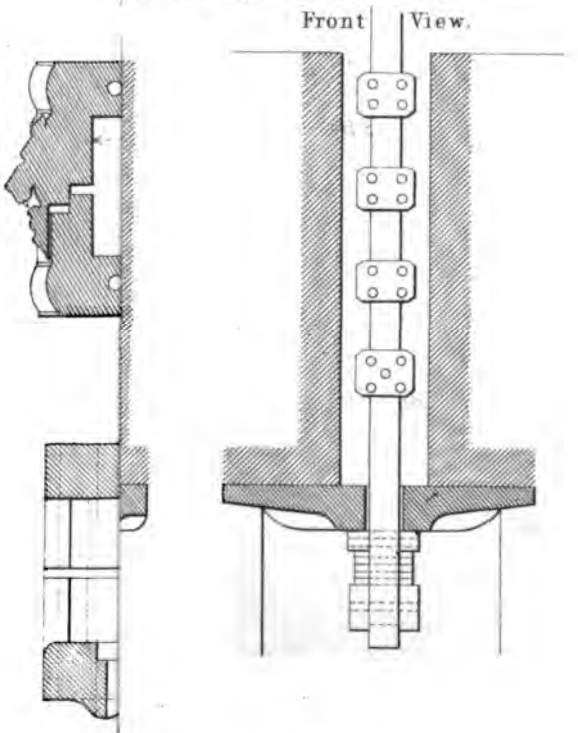
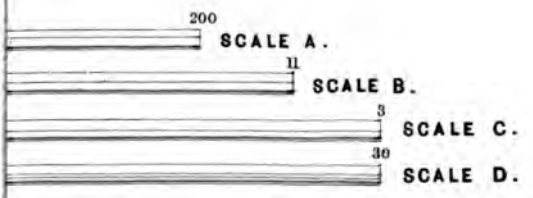


of fixing ends of Cables.





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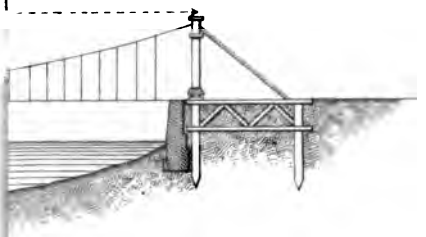
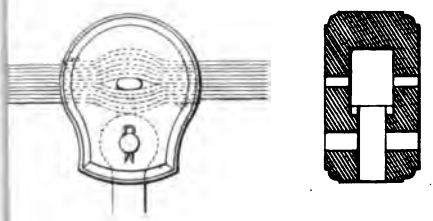
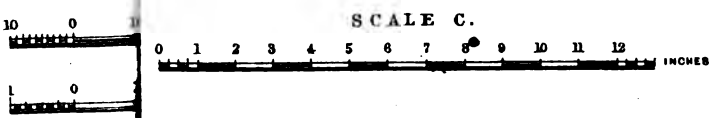
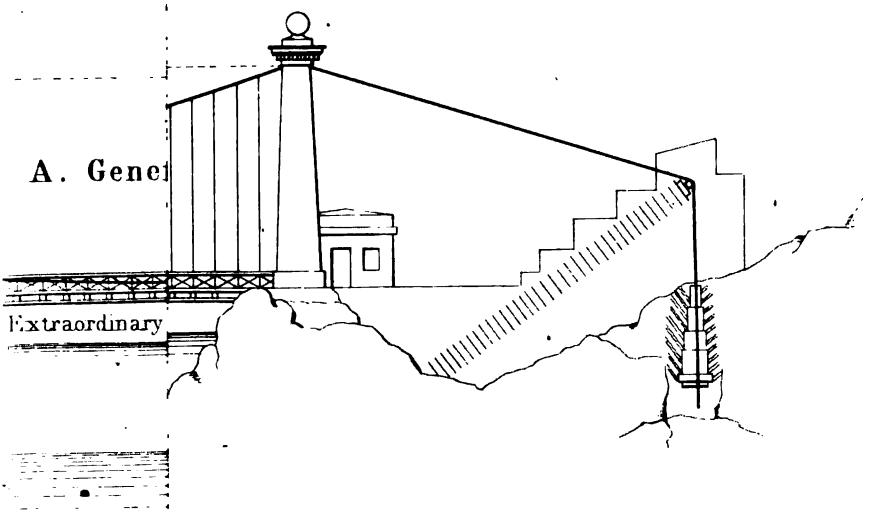


tails of Heads of Rods.







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A. Plan

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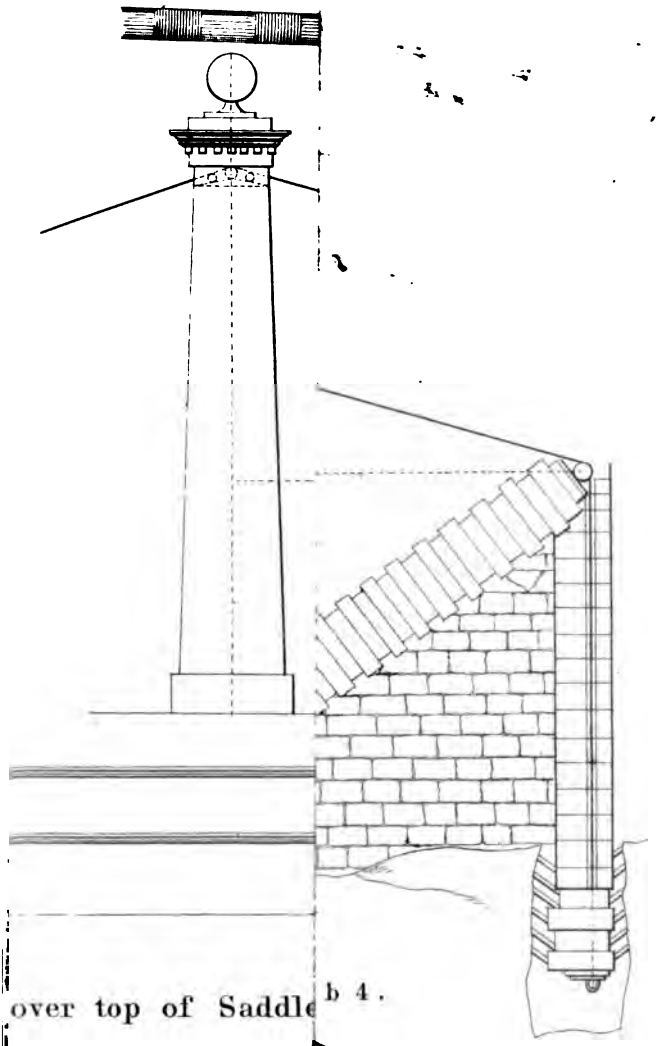
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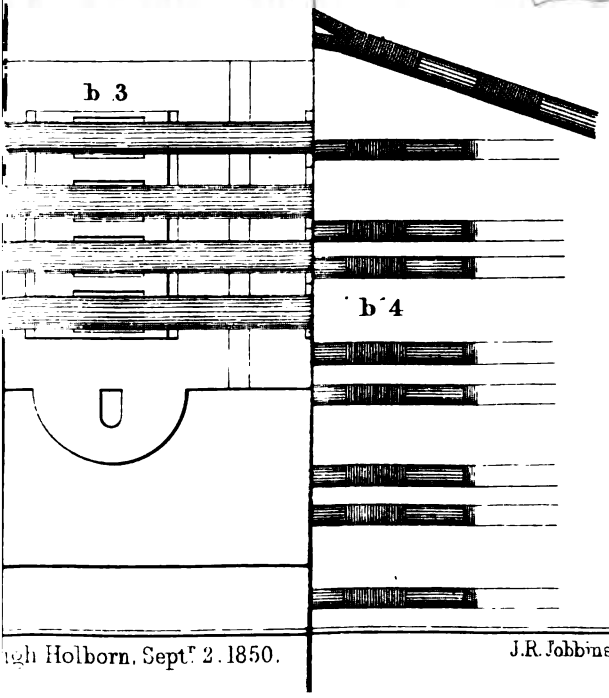
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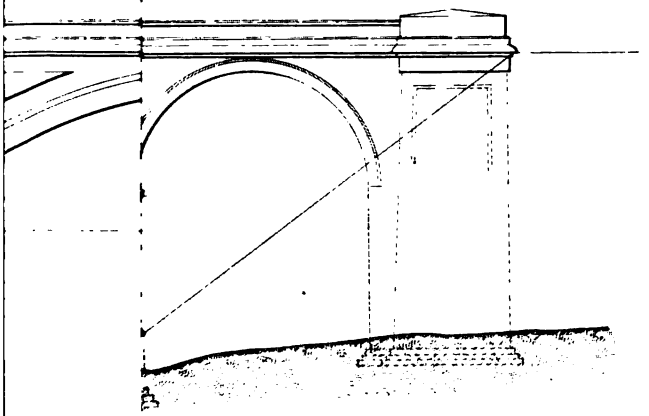

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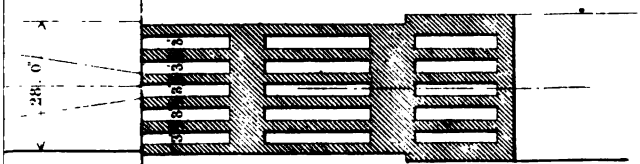

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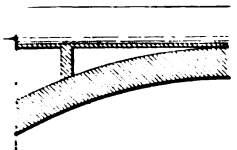
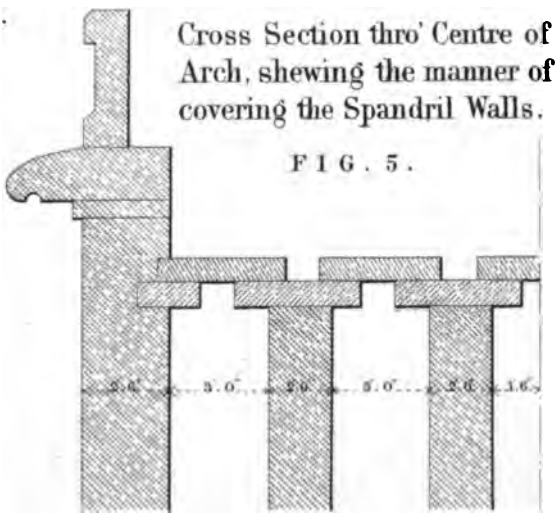


GOW & SOUTH WESTERN RAILWAY.

DGE OVER THE WATER OF AYR, NEAR BALLOCHMILE.

e of Arch.



Cross Section thro' Centre of Arch, shewing the manner of covering the Spandril Walls.

FIG. 5.

REPORT ON PESTH BRIDGE.

THE experience of modern nations in everything relating to bridges is so various, that no one of them can be said to have exhausted the subject. Climate, temperature, locality, the velocity of the rivers, the condition of their beds, and the materials used for bridges, determine, in some measure, the experience each nation has acquired; and owing to the above circumstances, one nation may surpass another in some particular branch of practical mechanics, though, in other respects, less advanced. In a country where the winters are mild, the rivers rarely or ever frozen, and no run of ice in fearful and devastating masses,—where the banks are high, where stone is cheap and money abundant, matters assume a different aspect compared with a country where the winters are severe, the climate variable, the banks of the rivers low, and stone, especially of large dimensions, dear. Thus, in the North American States, for instance, where much damage and danger ensue on the breaking up of the ice in the rivers, bridges with stone piers and timber arches, of immense span, become indispensable, and are made of great strength and solidity, timber and materials being cheap in that country; whereas, bridges of stone and iron are best adapted to England, where the rivers are rarely frozen, the banks generally high, stone and iron comparatively cheap, and money easy to be obtained. In Russia and Northern Poland, where the winter suddenly sets in, and as suddenly breaks up, bridges of boats are usually adopted, and found to answer best. There the custom is, instead of removing the bridge, on the appearance of ice, to leave it to its fate, and, on the return of spring, to substitute a new one. The damages done to the old are repaired during the summer and autumn, and such portions as

are found serviceable reserved for future occasions. Other considerations must be taken into account, when it respects the load a bridge has to sustain, viz.: whether the bridge be intended for foot passengers only, or for general traffic; and whether that traffic be small, regular, and slow, or great, irregular, and fast.

It is our opinion, that upon these principles and conditions alone, and of course with reference to material and design, &c., every bridge ought to be constructed; for instance, suppose it to be possible that any one could be found to propose such a bridge as now exists between Malta and Gozo, which consists of a single rope only, as a means of forming a permanent and safe communication, between the suburb of Unter-Maimhartsberg and Vienna, and offer as a reason, that because it answers in its present site, it ought, therefore, to answer in the proposed one, we might justly ridicule the idea and consider it pure folly. Keeping these general conditions in view, it is our opinion that a permanent bridge between the two cities of Pesth and Buda must not be a matter of taste only, but of demonstration according to the laws of mechanics and mathematics.

The main question is, what kind of bridge ought we to have? Now to answer this without further waste of time, by remaining at home, and deceiving ourselves with the beauties and subtleties of theory, we determined on going to England, and there consulting with men of experience and skill. The reason for our proceeding to England in preference to other countries, we beg to be allowed to explain, was partly because all that relates to mechanical science has been there brought to the highest development; partly because, in this respect, practical results are almost without end: or, to speak more clearly, because far more has been done there worth going to see, than is to be met with on the whole continent of Europe; but principally for the reason that it stands in such close relations with North America, a country whose climate and other physical characters bear so striking a resemblance to those of our native land. We could have desired no greater pleasure than to have visited that country, but the approaching opening of our Diet so limited our time, that, independently of other reasons, this, of itself, would have prevented us; therefore, in order to make the best use of the short time

allowed us (a few months only), we chose England, as presenting the best and widest field for our researches.

According to our views, and as far as our limited experience enables us to judge, the chief difficulties to overcome are: 1st, the force of the ice and the inundations likely to arise from the contraction of the sectional area of the river, where naturally the shores lie so low, as, for instance, at Pesth and Buda; 2nd, the raising of the necessary capital, with a financial system so poorly developed as ours; and, 3rdly, the absence of a general co-operation in carrying out great undertakings.

A bridge which could be constructed without any piers in the river, or with the least number possible, we consider the most desirable; and, in fact, in our opinion such only ought to be adopted. This desideratum, at least as far as present invention has advanced, is comprised solely in the Suspension Bridge, where facility of construction, strength, and durability are combined with cheapness and economy. At the first outset, we sought to put ourselves in communication with men who made work of this kind their chief study, and who had turned their entire attention to the perfecting of the branch of art adopted by them, and whose existing works were sufficient proof of their skill and ingenuity. Although we cannot omit to mention with praise the politeness and affability with which we were in general received, still, in justice to ourselves, we may allude to the difficulty we experienced at the commencement in drawing attention either to ourselves or to the greatness of our object,—the real cause of which was, that the principal engineers of England, being continually engaged in works of great magnitude, looked upon the erection of a permanent bridge between Buda and Pesth as a matter of little difficulty.

Added to this, we appeared as foreigners from a nation little known in England, without any certainty as to our plan being carried out; while, as honourable men, we could give no other answer to the invariable question, "Is it likely that the work will be proceeded with?" than, "We hope so."

We had, however, the satisfaction of seeing that the plans furnished us by the Directors of the Government Engineering department attracted considerable attention: these plans, for which we are indebted to the kindness of the Arch-Duke Palatine,

represented the course of the Danube from Waitzen to Földvár in all their detail, together with the necessary cross sections, and although we can with difficulty express the chagrin we felt when we discovered how little known we Hungarians were, by people in every other respect well-informed—still, on the other hand, we saw with pleasure the surprise expressed at the excellence and completeness of the plans, which they could not too highly commend. It must, however, be confessed that the ignorance of foreigners, with respect to us, is less to blame than ourselves; a heavy load lies upon our shoulders for our own backwardness, and it afforded us no small consolation when we saw the real value that was attached to our performances, for we thus clearly foresaw the dawning of the success which must ultimately crown the exertions of our nation, and the first spark of that holy fire, which, if not crushed and trodden under foot, swells the breast of man and stamps greatness on a nation. This feeling then, although it may be considered of little consequence, was to us of the greatest importance, for exactly in proportion as our undertaking created sympathy (which it was evident did not result from idle curiosity, but from a real desire to serve our native land), so did our zeal and endeavours increase. In mentioning these circumstances, we beg to return our sincere thanks for all the information we obtained in reference to our project, and to request the Honourable Committee to thank in the most marked manner His Imperial Highness the Arch-Duke Palatine, as well as the Honourable Board of the Government Engineers; for we feel that to the correctness and perfection of the plans furnished by them as above alluded to, we owe the obtaining of the information which we are about to lay before you.

Mr. W. Yates was the first with whom we communicated on the subject, and in order to enable the Honourable Committee to judge of the truth of our remark, viz. "How difficult it was to engage the attention of the English engineer for any undertaking, which although it might appear almost impracticable to us, appeared to him as trivial," we beg to be allowed to lay before you the following statistical data, which we purpose availing ourselves of occasionally for comparison in the course of this Report:—

Mr. W. Yates is a partner in the firm of Walker and Yates,

gentlemen who are proprietors of an iron-foundry capable of converting and turning out weekly 200 tons of their own pig-iron in addition to 200 tons of bar-iron, making a total of 400 tons of iron manufactured weekly, which, by a little extra exertion, as they assured us, might be increased to 500 tons. Notwithstanding that they own several coal mines, and that their works are situated at Gospel Oak, near Birmingham, in a comparatively cheap district, still their monthly expenses amount to 12,000*l.* The Viceroy of Egypt, alone, has paid them for many years successively the sum of 100,000*l.* From this it will be seen, that two English gentlemen produce more iron from their private establishment, in one year, than does the whole of Hungary in a similar period; for we find that the produce of manufactured iron, taking into account every place under the crown of Hungary, amounts to no more than 300,000 centners, or about 16,500 tons. As regards the extent of the works of Messrs. Walker and Yates, they are very far from being the largest in England, and the reason why we applied to them in preference to others was, that all the largest cast-iron bridges of the day had been made at their works, and because it does not necessarily follow, that they who do most work do it best. The average quantity of iron annually manufactured in Great Britain is 500,000 tons, but a few years back the quantity was nearly 700,000 tons. The Waterloo Bridge cost one million sterling, and London Bridge about 1,200,000*l.* The railway between Liverpool and Manchester, which is about thirty-two English miles, or about seven Hungarian, was (if we remember rightly) estimated to cost one million sterling, but actually cost 1,200,000*l.*; the distance is travelled over in one hour and a quarter. The railway now projected between London and Birmingham is estimated at 2,400,000*l.*, but it is believed will cost 2,000,000*l.* The proposed erection of a pyramid which should contain 5,000,000 of corpses, is estimated to cost from 400,000*l.* to 500,000*l.* sterling.

Through Mr. W. Yates, we became acquainted with Mr. Tierney Clark, an engineer of whose talent and experience we could have no doubt, particularly in all matters relative to Suspension Bridges. He has erected the Hammersmith, Shoreham, and Marlow Bridges, the plans and drawings of which, with a description, we have the honour to lay before the Honourable Committee.

From this time forward we obtained much experience and information, and omitted no pains to elucidate more and more the practicability of our project. We subsequently made the acquaintance of other engineers of eminence, amongst whom we may mention Mr. James Walker, the celebrated Telford, Messrs. Hartley, Ogden, (the American Consul at Liverpool,) and Mr. Wright, from North America; and, in the course of this Report, we shall have several opportunities of referring to the opinions of these gentlemen in detail. Our progress was recorded daily in our note-book; and, from the tenor of our inquiries, we soon became convinced that the practicability of erecting a permanent bridge between Buda and Pesth was no longer doubtful; and although we admit the necessity of having recourse to men of first-rate experience, its success must ultimately depend upon the will of the Hungarian nation. We could come to no other conclusion: why should we despond, with the example before us of a country where, amid the blessings of universal freedom, each step leads to new wonders, the fruits of man's genius, presenting a noble beacon to all other nations?—why should we entertain a doubt, then, but that in Hungary, too, we were capable of producing such noble works as in England are to be found in great numbers, and which, as monuments to the enterprise of private men, are to be met with continually? Yes; we cannot but be convinced such things are for Hungary too; if not, at least, in so great a number: we require but the will of the nation for a few. We were, however, fully impressed with the feeling that, for the furtherance of our object, it required more than merely to convince ourselves and the Honourable Committee—it required that our data should be such as would convince the public at large, and put the practicability of the structure beyond a doubt.

The carrying out of our project never, in reality, appeared impracticable to us; but what could we inexperienced individuals do, other than investigate the matter to the utmost, and, by sound proof, clear away the mist which seemed to obscure the understandings of contending parties? It now lies in the hands of the great public to solve this problem; we must, however, admit, that the public ought not to be induced to stake their money and their rights upon an object, the carrying out of which is hazardous and fraught with danger: therefore, to remove all doubt upon this

point, we consider the best and simplest method is to lay before them accounts of similar undertakings, all of which have been crowned with success. For this purpose, then, we beg most respectfully to lay before you a variety of designs of English bridges in existence, and of such as we have been able to obtain, and which in our opinion are best suited for execution between Pesth and Buda. First of all, we requested several engineers to favour us with their answers in writing in respect to certain queries which we had drawn up on paper, and which, as a more business-like way of proceeding, would at the same time enable the parties to consider their answers better, and moreover, avoid all ambiguity upon such an important point, and set at rest the scruples of those who choose to read them. Had we not adopted this mode of proceeding, it is possible that many might have been found ready to persuade others that we had been led astray by our enthusiasm for the cause, and wished them to believe as we did.

There is now, however, no room for such a belief, for we have the pleasure to lay before you the well-considered opinions of men, whose experience, far from being based on theory, is founded on actual practice, and who value their own reputation too highly to risk an opinion which they cannot afterwards support and demonstrate according to the laws of science. We therefore beg to lay before you a translation of the questions sent in to Mr. Tierney Clark, C. E., with his answers to the same.

The Questions as proposed by the COUNT GEORGE ANDRASSY *and the* COUNT STEPHEN SZÉCHENYI *to* W. T. CLARK, C.E., *together with his Answers, respecting the erection of a permanent Bridge between* BUDA *and* PESTH, 15*th September*, 1832.

First Question.—What kind of bridge would you recommend as being the best adapted for forming a permanent communication between the two cities of Buda and Pesth?

Answer.—I am of opinion that the description of bridge best adapted for either of the situations represented by the various plans and sections, for forming a permanent communication between Buda and Pesth, is a chain suspension bridge; as the limited number of piers it would require would oppose less obstruction to the flow of the water and ice than either a cast-iron or stone bridge. The approaches or ascent to a suspension bridge will be considerably less than those which would be required for either a cast-iron or stone bridge, and will consequently be cheaper in this respect. By referring to the sections of the river, it is evident that whatever the kind of bridge, the approaches must be of considerable length and height. To accomplish this it will require considerable outlay, which, however, may be much reduced by a judicious application of a dredging machine, to clear out the bed of the river; which, if I may be allowed to judge from the very perfect plans before me, would easily admit of very great improvement: so that, at the same time that you save money, you are carrying out a great public benefit.

Second Question.—Which is the largest suspension bridge in the world, and which has the greatest span between the piers?

Answer.—The greatest distance between the points of suspension of any bridge in existence is, I believe, the Menai Bridge, which is 570 feet; but the total length of the roadway supported on the chain is only 542 feet. The distance between the points of suspension of the Hammersmith Bridge is 422 feet; but the length of the roadway supported by the chain is 710 feet, or 168 more than is supported by the Menai Bridge.

Third Question.—What point between Buda and Pesth do you consider as best adapted for the erection of a bridge?

Answer.—It is difficult to determine which is the best situation between Buda and Pesth for the construction of a bridge without a personal inspection of the different sites from which sections have been taken; but any point between the sections *A B* and *a b* seem favourable. Below this the river widens very much, and the expense would be considerably increased without any apparent advantage.

Fourth Question.—Could not a bridge of one single span be thrown across

the Danube? And what do you consider the greatest length of space which could be adopted safely, and without disagreeable oscillation?

Answer.—A bridge could be erected over the river at any of the narrow sections to the extent of from 1000 to 1200 feet in one span, without danger or unpleasant oscillation; but I should advise having a bridge with two spans in preference.

Fifth Question.—How many piers do you consider it necessary to have in the water, in order to make a suspension bridge safe?

Answer.—The number of piers will entirely depend upon the situation which may be chosen for the erection of the bridge.

Sixth Question.—Do you not think that the ice would carry away the piers; for at times its force is beyond all conception?

Answer.—If the piers are properly constructed, there can be no danger of their being carried away by the ice, however massive and powerful it may be.

Seventh Question.—Would not the piers tend to an accumulation of ice, so as to impede the flow of the river, and thus cause serious and dangerous inundations?

Answer.—As all the ice and water passes through the narrowest section of the river at *C D*, and as the sectional area of the piers would be but small, the river between the sections *A B* and *a b* would still be equal in area, if not greater, to the narrowest section *C D*; and, consequently, there would be no increased tendency to the accumulation of ice.—(Having had a personal interview with Mr. Clark as to the purport of this answer, we obtained the further following verbal explanation, viz.:—that he could in no case recommend a bridge to be erected at the narrowest part of the river, either with one or more piers, since by such means the danger of increasing the accumulation of the ice would be great, and perhaps be the cause of devastating inundations. To this we made the remark that, although the breadth of the river at *C D* was considerably smaller than at *A B*, or *a b*, still the river was much deeper, and therefore could carry off more water and ice than at any other point. He answered, with respect to the quantity of water passing off, Your views are right; but, as the ice, for the most part, floats on the surface, the result would be quite different. He, however, concluded by referring us to his *First Answer*, in which he called attention to the absolute necessity of deepening the bed of the river.)

Eighth Question.—Is there any probability of the chain by which the bridge is supported, breaking?

Answer.—If the chains are made with the best wrought iron, and the usual and precautionary measures be taken as to the quality of the material, workmanship, and proof by a constant supervision during their manufacture, and their section be proportioned according to the load to be suspended, there can be no danger whatever of the chain breaking.

Ninth Question.—Is there no danger to be apprehended of the piers giving way, and being pulled over?

Answer.—If the piers are properly proportioned to their load and other contingencies to which they may be subjected, and are built with the usual and necessary precautions, there is no danger whatever of their being thrown down.—(*Note:* We cannot omit here calling attention to the expression which Mr. Clark makes use of in the *Eighth* and *Ninth Answers*, where, in speaking of the strength of the chains, he says, "if the usual precautionary measures are taken;" and with respect to the piers, again he says, "if they are built with the usual and necessary precautions:" we think it necessary to explain what is here meant, and which cannot but be considered as an extraordinary proof of the manner in which professional works are conducted in England. Mr. Clark says, "usual manner;" now these words do not mean indifference or neglect, as we find the common interpretation to denote, but rather perfection; for were our works in this country to be carried out according to the every-day interpretation of the word "usual," I should feel very great objection to trust myself on a suspension bridge constructed under such supervision.

Tenth Question.—Might not the natural elasticity of the iron, when acted upon by stormy weather, occasion a dangerous amount of undulation, which, if not injurious to the structure itself, would appear dangerous?

Answer.—I am of opinion, from my experience in this country, that the vibratory motion of the bridge would not be injurious, nor excite apprehension, in stormy weather.

Eleventh Question.—Are you aware of the existence of any house that would undertake to ensure the bridge against the following, viz.:—

a. The ice carrying away the piers.
b. The piers in the water causing an extraordinary stoppage of the ice, and thereby serious inundations.
c. The breaking of the chains.
d. The giving way of the piers, or sinking of their foundations.
e. The existence of unpleasant vibrations?

Answer.—I do not know of any establishment in this country which would undertake to ensure against the risks referred to under the heads *a, b, c, d, e.*—(*Note:* Mr. Clark could give us no satisfactory answer to this question. As engineer, he did not interest himself in the arrangements of assurance companies. We shall, however, further on, again refer to this question.)

Twelfth Question.—What do you consider would be the weight of the chains for a bridge between Buda and Pesth?

Answer.—The weight of the iron-work will entirely depend upon the span of the bridge, its versed sine, and the load the bridge will have to support. But before this question can be answered correctly, the situation of the bridge must be finally determined. In order, however, to place in the hands of the Company something tangible, until the time arrives for commencing

the works, and in order that they may be able to estimate their means, I have prepared several plans, with rough estimates, the estimate being computed according to English prices.

Thirteenth Question.—Might not the iron-work be manufactured in Hungary?

Answer.—Not being acquainted with the nature of the wrought and cast-iron of Hungary, or the means the manufacturers have for making the links, and other iron-work, with the degree of accuracy and precision so essential to the stability of a suspension bridge, it is impossible for me to give a decided opinion on this point; but, judging from the iron-work usually made abroad, I should think it could not be done without considerable risk and danger.

Fourteenth Question.—Of what kind of iron should the bridge be made—of cast or wrought iron?

Answer.—The chain links, vertical rods, pins, gudgeons, and bolts, must be made of the very best description of wrought iron, and under continual supervision, and subject to proof. The beams, truss-columns, retaining-plates, &c., should be made of cast-iron, of the very best grey pig.

Fifteenth Question.—What would be the price of such iron per ton?

Answer.—The price of the wrought iron work in London would be about 24*l.* per ton; the cast-iron work, about 10*l.* per ton.

Sixteenth Question.—What would the expense of freight per ton be from London to Fiume, including loading and unloading, together with the insurance?

Answer.—The freight per ton, including insurance, &c., to Fiume, would be about 1*l.* 6*s.* 6*d.*

Seventeenth Question.—What is the tenacity per square inch of English iron?

Answer.—An inch square bar of English iron begins to stretch with a weight of from 10 to 12 tons, and breaks with from 24 to 27 tons weight.

Eighteenth Question.—How is the tenacity of the iron determined?

Answer.—The iron can be proved in a machine constructed of simple or compound levers. A graduated scale then attached, from which the tension the iron is subjected to, may be read off during any period of the experiment from its first stretching to the time of its breaking.—(*Note:* These two answers can be only properly understood after personal inspection of the machine in use.)

Continuation of Questions and Answers on the 20th October, 1832.

Nineteenth Question.—Of what length and breadth would the piers, which stand in the river, require to be; and how deep must the foundations be carried?

Answer.—The breadth, length, and depth of the piers will depend on the width of the carriage-way, the span of the bridge, the depth necessary for the foundations, the height above the highest water necessary for the navigation,

as well as the dip of the chains; in short, the site of the bridge must be fixed, before a correct answer can be given to the question.

Twentieth Question.—What stone would be required for building the piers?

Answer.—Any kind of stone that can be obtained in large blocks, capable of resisting the weight to be supported, and the effects of the weather.

Twenty-first Question.—What is the price of the stone, as used in England, for such works?

Answer.—The price of stone used in this country varies from 4*s.* to 5*s.* per cubic foot, which includes all expense in labour, setting, and dressing.

Twenty-second Question.—What is the price of labour in England?

Answer.—The price of manual labour varies in proportion to the ability of the labourer.

A Mason is generally paid from			5*s.* 6*d.*	to 6*s.* 0*d.*	per day.
A Bricklayer	„	„	5*s.* 0*d.*	„ 5*s.* 6*d.*	„
Smiths	„	„	5*s.* 0*d.*	„ 8*s.* 0*d.*	„
Carpenters	„	„	5*s.* 0*d.*	„ 6*s.* 6*d.*	„
Common Labourers		„	2*s.* 6*d.*	„ 3*s.* 6*d.*	„

Twenty-third Question.—Would it not be advisable, for the greater security of the structure, to erect ice-breakers in front of the piers?

Answer.—The piers of themselves would form buttresses or "cutwaters," and be quite adequate to resist the effect of the ice, without any other assistance whatever.

Twenty-fourth Question.—What is the most desirable kind of foundation on which to build such piers?

Answer.—Rock of sufficient solidity, strong clay and gravel.

Twenty-fifth Question.—Would it not be advisable to protect the masonry of the piers by means of a cast-iron covering?—This is not proposed because we have any fear of the force of the ice, but because we feel a little anxious as to the stability of the piers when the chain comes in contact with them.

Answer.—This precaution I consider to be wholly unnecessary, because the chains are not fastened to the piers; but, on the contrary, only rest upon them on a system of rollers, in order to admit of their moving freely backwards and forwards.

Twenty-sixth Question.—Would not the structure be exposed to great risk, owing to the expansion and contraction of the chains under change of temperature?

Answer.—From the experience I have had, I am of opinion there is no danger to apprehend from the effects of heat or cold on the iron-work.—I am borne out in this opinion by observations made at St. Petersburg, where the mean greatest cold is 23° Fahrenheit below zero; and this intensity does not appear to have had any detrimental effect on the two small suspension bridges which are thrown over the Fontanka Canal, one being 184 feet between the points of suspension, and the other 150 feet. "If we only glance at the

construction of the different parts of a suspension bridge, we must at once lose all anxiety as regards its stability; for, as it will be seen by reference to the plans, the chains hang free from one extremity to the other, and consequently are capable of adjusting themselves, in case of any expansion or contraction taking place."

Twenty-seventh Question.—Do you think that the iron-work, in cases of thunder-storms, would be exposed to danger from electricity?

Answer.—I have never known any instance where the electricity has taken effect.—(*Note:* In England, thunder-storms are of rare occurrence; and as we do not consider this question superfluous, we shall take another opportunity of referring to it.)

Twenty-eighth Question.—Do you not consider it absolutely necessary that some experienced engineer should make a personal inspection of the proposed sites before the bridge is commenced; and would it not be further advisable that such person should reside a winter at Pesth, in order to see the effects of the breaking up of the ice?

Answer.—Certainly; I think that the most proper person to go over would be the person who might be entrusted with preparing the design; and I think this could not be efficiently done without taking a view of the spot.

Twenty-ninth Question.—Supposing it should be determined to erect a suspension bridge, would you have any objection to undertake its construction?

Answer.—I should have no objection whatever to undertake its construction.

Thirtieth Question.—In the meantime, until the whole is decided upon, would you undertake to furnish us with several working designs, and the necessary detail drawings?

Answer.—Yes, provided I am engaged to undertake its erection.—(*Note:* By these plans Mr. Clark understands drawings, which should denote the minutest detail, and the preparation of which requires so much time, that no one in the profession could be found who would undertake them, without having, as a remuneration for his trouble, a share in the construction of the work, or be handsomely paid. To prepare plans in England is so expensive, that our private Hungarian purses would have been inadequate to pay for them. We therefore considered it advisable to give up the idea of procuring a complete set of detail working drawings; first, because the actual site of the bridge was not fixed upon; and secondly, because we were not certain of its being actually carried out. Under these circumstances, therefore, we deemed it advisable to procure a general design only, but one which would at the same time be comprehensive, and give a general idea of the plan proposed.)

Thirty-first Question.—What would be the cost, including all contingencies, of a suspension bridge, supposing it to be erected at the section *A B* or *C D*, according to your English prices?

Answer.—According to my computation, a bridge, according to the design

marked No. 1, would cost about 143,000*l.*; according to the 2nd design, about 151,000*l.*; and according to the 3rd design, about 127,761*l.* sterling. I must, however, be allowed to observe, that these calculations are only so far correct, inasmuch as the sections are right; and every allowance must be made for the natural difficulties of the locality, which are wholly unknown to me.—(*Note:* This is the reason why we wished the prices calculated according to English ones, for by that means we could readily form a comparison by obtaining the relative prices of labour and material in this country, as compared with England.)

Thirty-second Question.—What do you consider would be the annual cost of keeping a suspension bridge in repair?

Answer.—I cannot undertake to answer this accurately, it depends on so many different circumstances; but the total expense of keeping the Hammersmith Bridge in repair for the last five years has not exceeded 100*l.* per annum.—(*Note:* The cost of the Hammersmith Bridge was about 48,000*l.* the cost of repairs per annum, 100*l.*, and consequently not more than $\frac{1}{11}$ per cent. per annum.)

Thirty-third Question.—Is there any establishment that would undertake the cost of maintenance, or secure us against the possibility of the estimate being exceeded?

Answer.—I do not know of any such establishment.—(*Note:* This question has reference to *Question No.* 11, and, as there observed, we shall refer to it further on.)

Thirty-fourth Question.—What time do you consider necessary for the construction of a bridge between Buda and Pesth, from the day of agreement to the day of opening?

Answer.—Not being aware of the facilities the country affords for conducting such a work, I cannot answer this question; but I should think it might be completed in from three to five years from the commencement.

Thirty-fifth Question.—At what fixed periods must the payments be made?

Answer. — This would entirely depend on the agreement with the contracting party.—(*Note:* We shall take another opportunity of referring to this important question.)

Thirty-sixth Question.—Would it not be advisable to construct either a cast-iron or stone bridge in preference to a suspension bridge, if we take into consideration the great amount of traffic of all kinds which it would be impossible to restrain within limits; and the enormous force of the wind in storms?

Answer.—I apprehend that a stone or cast-iron bridge would, from the number of the piers necessary, cause very considerable impediment to the flow of the river and ice, and consequently cause more frequent and serious inundations than heretofore.

Thirty-seventh Question.—Do you consider it advisable to construct

suspension bridges in such exposed thoroughfares, as, for instance, between Buda and Pesth; and would the security of the bridge require a system of police, whose duty it should be to prevent too rapid movement on the platform, as well as too great a load being on it at any one time?

Answer.—A chain bridge can be made capable of resisting the force of storms, as well as any amount of traffic, no matter what its velocity. I think the intervention of the police might be of service, not to insure the stability or safety of the bridge, but to put down all excesses, and prevent damage to the works, as well as prevent accumulation of manure and dirt on the platform.

Thirty-eighth Question.—Is the iron-work liable to be deteriorated by the effects of corrosion, and thus endanger the permanency of the structure?

Answer.—The iron-work will suffer little or nothing from corrosion, as it is usually protected from the action of the air, in the first instance, by heating, and then submersion in a bath of boiling tallow, after which it is painted with three coats of good paint. This method has been found to answer perfectly, so that one or two coats of paint, once in two or three years, according to circumstances, has been found to answer the purpose of preventing oxidation; and this method is attended with little expense.

(SIGNED) W. TIERNEY CLARK.

Hammersmith, 10th November, 1882.

Such, then, are the answers handed in to us by Mr. Clark; if, however, there should be any want of logical arrangement in the foregoing, we beg that the Honourable Committee will attribute it to the fact, that two series of questions were sent in, on two different occasions, the answers to which, for the sake of better reference we were unwilling to separate, are placed in succession under the same head; from which it will be seen that, in several instances, after an answer has been given, a question follows which appears to have no reference to the foregoing one. This, however, originated from the first answer containing reference to matters with which we were at the time unacquainted, and which we could not have foreseen. On the other hand, we must also beg to excuse the broken and disconnected manner of our investigation, on the plea of having had to make use of the English language, in which, at that time, we were not very great adepts; and, further, the reason that our inquiries were not so comprehensive as they might have been, we must again beg to observe, was, that having undertaken this investigation on the score of good-will, we lacked the courage, or, if we might so express

ourselves, the pedantry to heap searching question on question, and because we saw that Mr. Clark could badly afford to abstract so much of his time from his other great works to investigate a project at the time in embryo only. We had enough to do to get Mr. Clark to give us the few answers herein alluded to, which will be fully appreciated, when we assure the Honourable Committee that, notwithstanding our continual exertions and pushing, nearly two months had elapsed before we obtained the answers and plans we have now the honour of laying before you. We have, however, now the satisfaction, until the proper time arrives, of possessing in manuscript the opinions and views of an engineer, who, although he has neither grown grey nor old in his appearance (he is in the prime of life), still possesses as much practical knowledge as any other; and, although silent upon this point himself, still his works speak loudly in his praise.

This autograph we shall always consider, as a valuable result gained by our indefatigable exertions, since we hope and trust that the opinions of a practical man, of acknowledged talent, cannot but tend in a great measure to unite the views and opinions of those who consider our scheme impracticable, and our trouble as thrown away; and let us further hope that all well-wishers to their native land will join hands, and give us their united influence, with the determination to carry out and complete this undertaking, and not allow themselves to be led away by their prejudices. If, then, the opinions of such an experienced engineer can have no weight, what weight ought to be attached to the prattle of the wise-heads of the Coffee-house, who never in their lives saw a good bridge, and who, although they set themselves up as the champions of theory, have never so much as erected a gangway, nor a paltry wooden bridge, but who still feel themselves competent to dispute the possibility of a bridge between Buda and Pesth; and why? because they would be sure to fail in the erection of such a work.

It may, however, be urged in opposition to Mr. Clark's knowledge and experience, that as all his works have been confined to England alone, where, in comparison with our country, there is no winter and no great rivers, it is impossible for him to appreciate the enormous force of the Danube in winter; and in consequence, if we may be allowed to use the expression, his experience is

English only. Mr. Clark, too, was of this opinion, so that when he, in conjunction with Mr. Yates, was called upon by the Russian Government to erect a suspension bridge and other works at St. Petersburg, they commissioned Colonel Colquhoun, of the Royal Artillery, to proceed to St. Petersburg, in order to make observations on the temperature, the freezing of the Neva, the breaking up of its ice, its velocity, &c., and numerous other important matters.

From this fact we must consider his experience and knowledge as extending not only to England, but to Russia also, and, therefore, in some measure to Hungary; for, although with us the cold is severe in the winter, and our Danube a mighty river, yet in St. Petersburg the winter is by no means warm, nor the Neva a petty stream.

Notwithstanding all this, we considered it of the first importance in such matters to procure the very best opinions possible for our guidance, and, in consequence, did not confine ourselves exclusively to Mr. Clark; but, on the contrary, submitted the principal questions to other eminent engineers. With Mr. Telford we had, therefore, the following conversation:—

Question.—We wish to construct a bridge in Hungary, the length of which may be taken at 1600 feet. There are many of us who consider such an undertaking impracticable, and think that it would be either carried away by the ice, or cause such a stoppage in the river as to occasion extensive inundations. What is your opinion?

Answer.—It is difficult to answer this question at once, without a previous knowledge of the locality.

Question.—What do you consider the depth of the river? and what is the nature of its bed?

Answer.—Five to six fathoms, with a bottom chiefly of sand. The depth is insignificant; but the sand! the sand! that is a great evil.

Question.—And why? Is it not possible to overcome this difficulty?

Answer.—Why not? we have means enough at our command to provide against it; but rock or clay were better. For the rest, you need not have the least apprehension of stoppage to the ice, or inundations in consequence, if due precaution be taken to have the supporting piers at a sufficient distance from one another.

Question.—What kind of bridge would you recommend? and what do you consider as the greatest available span, and at the same time the least dangerous?

Answer.—This can only be determined from a knowledge of the locality; suspension bridges admit of the largest spans. I have prepared a design for

the city of Glasgow, of a bridge a 1000 feet span; but I consider spans of from 500—600 feet (like those of the Menai Bridge, which I built) to be the most advantageous. The piers of this bridge would not care much about the ice of your rivers; they would laugh at it. With respect to the effects of the ice, I have a great deal of experience, having constructed many bridges in Scotland, where the natural difficulties have been greatly increased, owing to the velocity of the river and the force of the ice. But, Gentlemen, allow me to observe, we do not consider any thing impossible. Impossibility exists only in the prejudices of mankind, to which some are slaves, and from which few are able to emancipate themselves, and enter on the path of truth.

Question.—While on your bridge at Menai, we did not experience any extraordinary motion, although men, carriages, and horses were passing and repassing; but when only six men ran along the platform, each keeping step, we did experience a sensible motion. Would not, therefore, this kind of motion be much greater in a bridge between Buda and Pesth, where the traffic is many times greater, and where the river is so much wider, than at the Menai Strait? [*Note:* The drawings of this bridge we now beg to lay before you.]

Answer.—Suppose the bridge to have a little motion, it is of no consequence, and can do no injury; so that, notwithstanding the great traffic between Buda and Pesth, I do not consider that you could construct a safer kind of bridge; however, should it be necessary to avoid motion altogether, then I should recommend you to erect a cast-iron bridge of three spans, each 400 feet; such a bridge will have no motion, and though half the world lay a wreck, it would still stand. The three piers, which would thus be necessary in the river, could in no case require more than a width of 75 feet; and, while they would be irresistible to the strongest ice, they would not occasion any extraordinary inundation in so broad a river. Whether you have sufficient money for such a bridge, is quite another question, and one which I cannot answer. I will, therefore, confine myself to this observation, that the cost of a cast-iron bridge of three arches would be, at least, double the cost of a chain bridge, since for the latter a less number of piers would suffice. The bridge over the Menai Strait did not cost much more than 70,000*l.*

Question.—Does the maintenance of the Menai Bridge require much outlay?

Answer.—It requires nothing more than now and then a fresh coat of paint. The piers are hollow, so that their internal structure may be seen, and examined at any time.

Such was the result of our conversation with Mr. Telford; but as he had not the time to answer our questions in writing, we took the precaution to make him understand, in as clear a manner as

possible, that we considered his opinion as proceeding from a great authority; and that in making our report we should commit his conversation to writing, and that in consequence he must be prepared to substantiate his opinions. This he readily consented to, and, therefore, we are now in the position to lay before the Honourable Committee the authentic opinion of Mr. Telford for its further satisfaction, since we can pledge ourselves to the correctness of our questions, and also of his answers, as given above. In submitting the foregoing, we beg to observe that we consider it of the greatest importance to the success of our undertaking, that the opinions of Messrs. Telford and Clark entirely agree as to the two main questions, viz., that the ice will not carry away the piers, and that the piers will cause no serious inundations. Not being yet satisfied, we sought to avail ourselves of the experience of such men as lived in countries where the winter was severe, and where rivers similar to our Danube existed. We, therefore, proceeded to Liverpool, and put ourselves in communication with Mr. Ogden, an experienced mechanician, consul for the United States, at that port. After fully discussing the subject with him in all its bearings, the result of our interview was that a bridge might be built between Buda and Pesth, but that the undertaking would be attended with great difficulties. We therefore drew up a list of questions which we sent to him, requesting his answers in writing; and we have now the pleasure of laying them before the Honourable Committee, verbatim as we received them from him.

Our Questions.

Since the climate of Hungary bears a great resemblance to that of the Northern portion of the United States, and since the natural features of its rivers do not differ much from those of the Danube, what do you consider the most desirable kind of bridge for forming a permanent communication between the cities of Buda and Pesth, the breadth of the river being about 1600 feet?—[*Note:* The reason of our having given 1600 feet as the width of the river was, that the site not having been determined upon, we thought it most advisable to be on the safe side, and assume a larger span. With a less span the difficulty, of course, would not be so great. On the site of the present bridge of boats the width is only 1248 feet.]—Do you not consider that the piers in the river would be much exposed to the force of the ice, and be in danger of being carried away? What amount of experience do the

Americans possess in this respect? Does the experience in America prove that the piers cause a stoppage of the ice, from which extraordinary and dangerous inundations ensue? Which is the longest and most complete bridge on piers in America? Do you believe that iron bridges are much exposed to lightning? And is it true that from this cause such bridges are not adopted in America? What do you consider to be the greatest available span with perfect security? What is the reason that the American bridges in general are constructed of wood, and not of iron?

Mr. Ogden's Reply.

When good timber can be procured cheap and in abundance, I consider that bridges with the superstructure of timber resting on stone piers, with the approaches also of stone, offer more advantages than any other kind of bridge, no matter of what material. A bridge on this principle was constructed about 30 years ago over the river Delaware, at Trenton, and stands to this day in the most perfect state. This bridge was constructed on the suspension principle, with spans of 200 feet each, so that in case of repair being necessary, each piece could be taken out and replaced without interfering with the stability of the bridge. In the spring, when the floods begin to accumulate and the ice to break up, the piers are exposed to great danger, which, up to this time, they have so gallantly withstood, that on this point we have now no fear.—[*Note:* In Mr. Ogden's letter he has described, in complete detail, the construction of the Delaware Bridge, which, however, we have omitted from our report, because we have the honour of laying before the Honourable Company his original letter, together with a drawing of the bridge.] In answer to the *Second, Third,* and *Fourth Questions,* I beg to state that no apprehension need exist of the piers being carried away by the ice, provided they be properly and judiciously constructed of suitable material, such as granite, than which there can be no better. Our American rivers are perhaps more exposed than the Danube to accumulation of ice and inundations; still experience has proved, that, notwithstanding that the piers are strong enough to resist the whole force of the ice, still their section is so small that the ice is not in the least impeded in its course, and in consequence does not occasion inundations. Every one is aware of the great rivers that are to be found in America—perhaps the largest in the world—still I do not think that one can be found over which there does not exist a permanent bridge. I could easily enumerate twenty bridges, all constructed of timber, on different, but still true, principles. For such a river as the Danube, I do not know that I could recommend one better adapted than the Delaware Bridge at Philadelphia. I consider an iron bridge to be quite as secure as any other against lightning, no matter of what material; for by means of a single wire connecting the bridge with the water, the destructive effects of electricity can be obviated. I am not prepared to answer the question, wherein you wish to

know the largest span timber arches admit of; but I believe they can be made equal to those of cast-iron.

The origin of timber bridges in America I attribute wholly to their extraordinary cheapness, which experience has demonstrated; and as they possess every advantage, so we find, even to this day, that out of every hundred bridges erected over large rivers, ninety-nine are constructed with timber superstructures.

And I am of opinion that the more demonstration you seek on this head, the more you will become convinced, that either a suspension bridge, such as is erected over the Menai Strait, or a timber bridge on the American principle, will be the best for accomplishing your object. The latter, however, deserves your best consideration, both by reason of its comparatively trifling cost, and from the advantage of its being free from oscillations, which in several instances have caused the destruction of suspension bridges.

In conclusion, allow me to propose that you might, with much advantage, proceed to America, there to convince yourselves of what has already been accomplished in this respect, where, provided it met with your approbation, you would find engineers willing to accompany you who would undertake the construction of a bridge between Buda and Pesth, and that, too, on the best and most approved principles.

(SIGNED) FRA. B. OGDEN.

Liverpool, 27th October, 1832.

On the 3rd of November, we again submitted the following questions to Mr. Ogden :—

Who in general finds the capital for the erection of bridges in America—the Government or private companies? If the Government, in what manner is the cost levied on the public? And, if the erection is intrusted to private companies, in what manner do they recover the capital expended? Is not the right usually granted to them of levying toll on all passengers, either for a stipulated number of years, or in perpetuity? And is there any bridge in the United States where no toll is levied? Are bridges in general a profitable investment? How many piers has the Delaware Bridge? what is its entire length? and what was the cost of erection? Do any police regulations exist for providing for the safety of the permanent bridge at Philadelphia, that is to say, for restricting the amount of traffic, which may pass over the bridge at any one time?

To which he gave the following answers :—

"In the United States such bridges as here alluded to are invariably erected by private companies. A right is granted to the company of levying a certain toll on all passengers, in compensation for capital, interest

on the same, and the cost of maintaining the bridge. Besides this, the law undertakes to protect the company against all infringement of its regulations, and gives them the power of enforcing their observance, so that no damage can be done by any one, either intentionally or otherwise; or by heavy burdens or quick driving, without falling under the severest penalties of the law. And since the maintenance of these bridges is always attended with considerable cost and continual repairs (provided that the tolls are such as do not yield an exorbitant profit to the company), it is the custom for the Government to grant the company the right of holding these bridges either in perpetuity or for a long term of years. Bridges over which there is a good traffic are considered good investments; but since the profits are not so much considered as the increased facilities of intercourse, a return of seven per cent. per annum is not considered to be an ample remuneration; and this is about the common rate of dividend to the speculators."

Mr. Ogden also promised to furnish us with several plans of American bridges, as well as to procure for us details of their cost and copies of the laws by which the shareholders were secured; he further, with the greatest politeness, offered us his services in anything he could be of use to us in, and concluded his letters with the following encouraging remark: "That we might rest assured, if we followed the right course, that the genius of our countrymen would at no distant day produce works, of which our country might be justly proud!"

We conferred in Liverpool with several other engineers respecting our scheme; amongst them, Mr. Jesse Hartley, who has a most extensive practice in the construction of cast-iron and stone bridges. Although he fully considered the power of the ice, still he thought that piers properly constructed would resist it with perfect safety. He was of opinion that inundations could occur only if the piers were constructed in the narrowest part of the stream, or if built so close together, and so low, that the inundating water and the floating masses of ice would be so much impeded, that in case the bridge were not carried away, it would act as a dam in penning back the water. Against suspension bridges he spoke with the greatest degree of prejudice, and his views were in part supported by an American engineer in London, with whom we afterwards became acquainted. This engineer was a Mr. L. Wright, a very young, but clever man, who, to our knowledge, had never constructed any work, but

who had completed a very remarkable model of a cast-iron bridge, which we examined with all due attention, and which, as far as we were able to judge, was well designed, on good and simple principles. The opinions of English mechanicians and men of science, however, were very conflicting; for while, amongst others, Messrs. Davis Gilbert, and Meredith approved of it, the celebrated Stevenson condemned it.

Mr. Hartley considered the oscillation of suspension bridges to be most dangerous, for, as he expressed himself, the least load would put the chains in motion. Owing to this cause he considers a bridge of cast-iron, with arches of 300 feet span, as the only advisable bridge for crossing the Danube at the proposed site. Mr. Wright also condemns the oscillation of suspension bridges: "If they did not oscillate, then," says he, "they would be the most perfect of bridges, for they admit of being constructed of almost any span, while their cost is comparatively trifling; but since their oscillation cannot be wholly avoided, (that is to say, up to this time no effective remedy for it has been invented), I consider them decidedly unsafe." According to his opinion, he should have no hesitation in recommending a cast-iron bridge on the principle of his model, with arches of from 600 to 700 feet span, as the most appropriate. Inundations and the power of the moving ice he did not fear in the least, and in order to avoid all waste of words on this head, he referred us to the numerous American bridges, which had been erected from 40 to 50 years ago, and which now stand in perfect repair, and which have never been found to cause inundations.

Mr. James Walker, one of the most experienced engineers and bridge builders, we had also the pleasure of consulting, but only during the latter part of our stay in England, owing to his extensive practice and engagements: we, however, did not receive a definite opinion from him, but as we had left our plans with him we expected one every moment. From the preliminary conversation we had with him, we think he is likely to give his opinion in favour of a cast-iron bridge (provided our means admit of it), and if not, of a timber bridge. With respect to the security of the piers, he fully concurred with those engineers already alluded to, and he felt convinced that they would not cause inundations if made high enough and at proper distances.

In an engineering point of view, it appears no difficulty exists, and although there is no difference of opinion as to the two principal questions, first as to the possibility of the piers being carried away by the ice, and secondly as to their being the cause of serious inundations; still, both English and American engineers were quite decided as to the kind of bridge they would recommend. In all that relates to the two principal questions above mentioned, we fully concur; for if we examine only for a moment the principle of construction of our own existing bridges at Dresden, Prague, Lintz, Wiener Tabor, and Esseg, it is impossible not to feel convinced that a bridge may also be erected between Buda and Pesth with one, two, or three piers, each from 24 to 30 feet thick, without any fear of causing an inundation. The bridges at Dresden, Prague, and Lintz, during high floods are no better than dams, their piers are so low and so close together that they barely afford room for the ice and water to flow through, and, notwithstanding, it rarely happens that they are either carried away, or that they cause inundations; their construction is, however, extremely faulty, while their great disproportionate strength, or rather too great thickness, is, in fact, their weakness, for since the water way is so much confined, in floods they have to bear the whole weight both of the water and ice. The bridge at Dresden, as is well known, has stood uninjured for a long series of years; on the other hand, not many years since, the bridge at Lintz suffered considerable damage, and if we are not mistaken, some of its arches were blown up by the force of the ice. Is it then to be wondered at, or rather, we should say, is it not perfectly natural, that many "bridges" called "good" should have been destroyed by floods and ice, over rivers which, in point of magnitude, are not worthy of comparison with the Danube? though it has given rise to such sayings as: "Because that insignificant stream has destroyed such a good and stable bridge, which appeared to bid defiance to centuries, it is therefore impossible to build a bridge over the Danube, which is a hundred times more powerful."

Let us, however, investigate of what kind this "good bridge" really was, and we shall find that it was, in fact, nothing more nor less than a pile of stones, some large and some small, heaped together without judgment, while the arches were so low and

badly constructed, that in the direct proportion as the water and ice increased, so did the obstruction. The consequence of having the piers low is, that the moment the water begins to rise and has reached the springing of the arch, the passage way decreases; and, thus, when the freest passage to the ice and water is required, the least is afforded, and the result is often similar to that which took place with the bridge at Lintz, where the ice, collecting under the low arches, and so impeding the flow of the increasing waters, blew them up, with a force inversely to that which would be required to break them in from above. Hence the general phrase, "It is impossible to build a bridge across the Danube," has become a password. According to this old-fashioned and faulty plan, the old London bridge was built, which at high water served as an actual dam in the proportion of 80 to a 100, while the opening or free passage for the water was as 20 to a 100. Again, the Wiener Tabor bridge —on what principle was it constructed? single piles were driven into the bed of the river with the most unwieldy and clumsy machines, the piles having often to be spliced together in order to reach the bottom, which had been washed out by the scouring action of the water, and notwithstanding the most indifferent workmanship, that feeble structure has lasted many years.

The bridge at Esseg is another example of this kind: it is built of timber, with the piers 78 feet only apart, and although a most serious impediment to the flow of the ice, it has now stood nine years without having suffered any damage worth notice. Let us now suppose, for example, that between the section *A B* and *b a* five piers, each 24 feet thick, and of such a height that during the greatest floods the surface exposed to the water shall not exceed 24 feet, be constructed; the width of the river at this point will then be diminished 120 feet, and if the width of the river be taken as equal to 1560 feet, we shall then have a clear water way of 1440 feet remaining; on these piers we can either erect a suspension bridge, or have arches of timber or cast-iron as we please. The span being only 240 feet, the oscillation in such a suspension bridge would be almost imperceptible, but, as is manifest, the whole quantity of the ice and water must pass through the section *C D*, which is only 1020 feet; we shall therefore have a water way on the site of the

proposed bridge at *A B* and *b a* 420 feet greater than tha at *C D*.

Let us next compare our solid, lofty, and well-constructed piers with the disproportioned, thick, and stumpy supports of the Dresden Prague, and Lintz bridges, or with the trembling, straggling supports of the Wiener Tabor and Esseg bridges. Then, if we bear in mind that the bridges at Dresden and Prague, with all their faults, have stood many centuries uninjured, and that the bridges at Lintz and Wiener Tabor have defied the ice and resisted its power, and then combine all these results, we shall be able to say with certainty that there is not a single insurmountable physical difficulty opposed to our ardent wish of uniting the two cities of Buda and Pesth by means of a permanent bridge.

Now, although the Danube at Pesth is indisputably broader and more powerful than the Danube at Vienna or Lintz, the Elbe at Dresden, the Moldau at Prague, or the Drave at Esseg, still water and ice must be subject to the same laws under nearly the same climate; and, as the engineers of the present day are one hundred times more skilled than those who constructed the bridges at Dresden and Prague, it follows of course, that if these piers have stood uninjured to this day, surely men of far greater experience can erect piers between Buda and Pesth which shall bid defiance to the mighty Danube; yes, and to far mightier rivers too! We shall now proceed to review the consequences attendant on carrying out our suggestions: at that point where we purpose to construct a bridge, as at section *A B*, *b a*, first we have proposed a bridge with five piers, each 24 feet thick on the highest water line, and which will be equal to a contraction of the width of the river of 120 feet. Now it may be apprehended that this diminution of 120 feet will cause frequent inundations, and if so, we beg to suggest the simple remedy of a less number of piers, for instance, only four, which will cause a diminution in the width of 96 feet only; this, however, is not sufficient to allay all fears, so we must beg to recommend the adoption of Mr. Tierney Clark's third design, where only one pier is proposed, which will cause a diminution of 42 feet only in the width of the river. Let us here pause a moment and ask the question whether it is probable any one will be found bold enough to stand forward and assert that even this single pier

will cause obstruction enough to lay the adjacent cities under water. No, we do not consider it possible; for on what principle can it be demonstrated that the ice, instead of flowing on through an unimpeded channel, should turn aside and pertinaciously adhere to this single pier?

Gentlemen, the very notion of such a thing is perfectly absurd. From this we may justly conclude, that, supposing a bridge with six arches to be objectionable, a bridge with two arches or with one pier only need not be so; and as no engineering difficulty is attached to the construction of a suspension bridge with one centre pier, we again come to the possibility of uniting the two cities. The important question now remaining to be decided is, what kind of bridge is best adapted, both with regard to our financial resources and the nature of the Danube: with regard to this object we beg leave to lay our humble opinion before the Honourable Committee, which we beg may in no way be considered as anticipating their decision; but from the fact that having devoted the whole of our time for many months to the consideration of this point, and having investigated and well considered the advantages likely to arise from the adoption of any of the existing examples, we think ourselves called upon to lay our unbiassed opinion before the Honourable Committee.

First, with regard to a bridge with stone arches, we consider the idea must be abandoned; for supposing we possessed the enormous sum necessary for such a work, it would not be applicable to the river, on account of the great number of piers required; and the limited height, owing to the lowness of the shores, would inevitably produce the most serious inundations. The largest stone arch to our knowledge is to be found at Chester, in the bridge which spans the river Dee—the arch is 200 feet span. The celebrated Rialto bridge at Venice has a span of only 90 feet. Now since the Danube at the section, *A B*, *b a*, is 1560 feet, if the span of the Chester bridge be adopted here, we should require six massive piers in the river, and the bridge would in consequence be raised too much, so that the approaches would nearly equal the whole length of the bridge, and owing to the locality could not be accomplished.

Before proceeding further, we must beg to assure our countrymen, that we are of unanimous opinion that no bridge which does

not at present exist, and which has not been fully proved by trial, ought to be recommended: were it otherwise, our time and money might be lost in experiments, which, if not attended with success, would have the double evil of retarding our advancing steps. We find that in a model many things are considered perfect which when carried out on a larger scale do not succeed; we therefore consider the best and most sensible plan for us is to follow and study closely the result of practice only, so that, instead of trying experiments for others' benefit, we may rather profit by past experience; and therefore we do not see that we can in justice to our subject recommend stone arches of 200 feet span, since we are not aware of the existence of another example of the kind. The centre arch of the new London Bridge is only 150 feet span, and the nine arches of the Waterloo Bridge are only 120 feet each in span; the latter, however, was considered by Canova, during his stay in England, as the greatest master-work he had seen, which for its beauty of proportion and symmetry exceeded all others ever built.

Secondly, with regard to cast-iron arches, we consider them much better adapted to the Danube, for it is not only demonstrated beyond a doubt, but practice proves it, that they may with safety be used in spans from 240—300 feet, and we cannot find a better example than the centre arch of the Southwark Bridge, which has a span of 240 feet; if, therefore, it were necessary, from four to five piers might be constructed in the river, where it is from 1320 to 1560 feet wide, without, as already stated, occasioning any inundations, as experience in America has fully proved.

Thirdly, with reference to suspension bridges, prejudice, and a natural dislike to them, are so strong, that it requires time to overcome both. The astounding appearance of the structure—the ideal and airy form in which it presents itself, tend (if we may so express ourselves) to overwhelm the senses, and to deprive man of his judgment; and it is not without much pleasure we acknowledge that our fellow-men have accomplished things we can with difficulty form any idea of. We had never seen such a structure; and we must acknowledge that our first impression on beholding it was but the reality of what we have here endeavoured to delineate. If surveyed from the side, and from a distance, it appears like the finest filagree work, and it is impossible to convince oneself of its

stability—we were particularly impressed with this feeling as we approached the Menai Bridge from Bangor, and beheld it, as it were, suspended in the air : we, however, soon found ourselves upon it, and surveyed with wonder the gigantic chains by which it was supported. In general the first impression that we received on beholding a suspension bridge was anything but agreeable—our eye and judgment, already well practised in determining the proportions of wood and stone, could with difficulty be brought to appreciate the disproportion of the iron, which from the strength of that material is small in quantity, and gives an appearance of weakness to the structure.

This feeling was particularly excited on inspecting such works in England; for instance, the interior of Covent Garden and Drury Lane Theatres. It is, therefore, not to be wondered at, if, at first sight, suspension bridges raised in us a feeling of doubt, for compared with other buildings in iron they appear much weaker, since the whole, if we except the piers and the platform, are wholly of iron, without any covering, and generally at a great elevation. Before our journey to England, we must freely admit that our prejudice against suspension bridges was very great, and we considered them as only available where the traffic was small, and consisted chiefly of foot passengers, who are more easily kept in something like order. The force of the wind excited also the most lively apprehensions, so that we considered it altogether as impracticable, to erect a suspension bridge, even with two or three spans, between Buda and Pesth, without, at the same time, having before our eyes the most frightful oscillations, and its total destruction. Now, however, that our eyes have become accustomed to judge of the proportions of iron structures, and that we have ascertained, with most extraordinary accuracy, how the smallest part of an iron bridge is prepared, and its great strength, and have seen numbers which have stood for many years without the slightest injury, and have beheld the traffic which daily and hourly passes over them, we are of a different opinion; we now consider them so secure, provided they are constructed as they ought to be, that if all we possessed—if even the prosperity and hopes of our Fatherland depended upon their safety—we should not have the least fear. As regards the force of the wind, we cannot but laugh at the groundless fears which our inexperience

had excited; we do not now consider that there is the least cause for such apprehensions: on the contrary, the construction of a suspension bridge is such that the surface exposed to the action of the wind is so small in comparison to its strength, that we consider any other structure much more exposed and liable to injury from the force of the wind. It is, however, well known that until within the last few years suspension bridges were in their infancy; and that the experience of the present day far exceeds that of a few years back, and in consequence we consider that those bridges erected on the Continent of France—especially at Paris—cannot be referred to as examples; and further, we should consider any person who would judge of those constructions from such examples, to be incapable of giving an opinion.

Fourthly, with respect to bridges with timber superstructures we can only speak theoretically, not having seen a single example which would be suitable to our locality. The experience of the United States, however, removes all doubt as to the possibility of constructing a timber bridge on stone piers between Buda and Pesth, for there are many existing bridges in America with spans varying from 200 to 250 feet.

From the foregoing, we arrive at the conclusion that three kinds of bridges admit of being constructed between Buda and Pesth with more or less facility; for we find both cast-iron and timber bridges, as well as suspension bridges, well adapted. As to which of these three kinds of bridges would be the most advisable under the existing circumstances, we beg to be allowed to lay before you our observations on that point.

Cast-iron bridges have not the least oscillation; and, to all appearances, are capable of defying time;—however, the largest span they admit of (that is, unless we wish to experimentalise) is from 200 to 300 feet; while, on account of the great thrust of the arches, the piers must be very massive; and in consequence would oppose more resistance to the flow of water than either a chain or timber bridge, which admits of larger spans with less massive piers. If the arches be very wide, and be constructed according to the circumstances of the locality; as, for instance, in our case; the arches, and consequently the approaches, must be very high and very long, which with reference to the Buda side should be carefully considered. The cost, too, of such a bridge may be taken at double

that of a suspension bridge, and most likely at four times that of a timber bridge.

Suspension bridges possess two great advantages, as compared with all others: First, they offer a far less resistance to the passage of the water and ice, because they admit of the largest span; and because the piers, upon which the whole load acts vertically, can be made small in proportion. Secondly, they require much lower approaches than all other bridges. This point deserves particular attention, when the magnitude of our river, the immense force of the ice, and the lowness of the banks are considered. Oscillation, on the other hand, cannot be avoided; and its effect upon large spans would perhaps require to be controlled in some manner, in order to prevent danger from inordinate loading, and the passage of vast numbers of persons on foot over it at the same time; this latter being the severest trial which can be applied to a suspension bridge. Besides, the greatest amount of cleanliness and supervision is necessary, since iron, when exposed to the action of the atmosphere, readily oxidises. This, in our climate, however, does not take place to the same extent as in others, where the atmosphere is more moist, and where, of course, iron is more rapidly acted upon. Lastly, bridges with timber superstructures are the cheapest of all permanent bridges; their duration without continual repairs is, however, short, and according to our opinions, or more properly according to our tastes, we consider they would not be approved of: they are constructed on the suspension principle, and require to be covered over, which prevents their being made use of as a promenade, for fresh air and exercise. The most appropriate site for the proposed bridge is the next consideration, and depends upon many circumstances, which require to be well understood (at least better than by us), before an opinion can be risked; we are, however, of the opinion that it would be by no means advisable to erect a bridge at the narrow part of the river between the Block's-bad and the point opposite, where one pier would be dangerous, since not one engineer in England recommends the adoption of a bridge of one span.

On the site of the present Bridge of Boats, a bridge could not be constructed without a considerable expenditure, because the banks are at this point very low, and as a bridge would require its approaches to be from 18 to 20 feet high, much ground would

be necessary, which, owing to the number of well-built houses here abouts, could not be obtained without considerable cost. Here, then, with regard to the mechanical part of our undertaking, we beg to close our Report. We have laid before you the opinions of several engineers, and have taken the liberty of adding our own; but as the most competent judges are not always of the same opinion, we have not ventured to do more than lay before you, in as faithful a manner as possible, the nature of the various bridges with their advantages and disadvantages as estimated by us.

Having, during the course of our travels, occupied ourselves in devising means for the carrying out of our undertaking, we must beg again to be allowed to trespass on the patience of the Honourable Committee, while we lay before them a few of our observations on this head.

Any one of the three bridges already described is practicable, if means can be devised for raising the necessary capital; from which it is evident the success of our project depends upon our financial resources.

According to Mr. Clark's computations, as already observed, the cost of a suspension bridge would barely exceed 120,000*l.*, the cost of a cast-iron bridge would be near upon 240,000*l.*, while a timber bridge would possibly not cost 60,000*l.* Without more accurate calculations, it is, however, impossible to determine this with any great degree of accuracy; it is impossible to furnish accurate estimates without a previous knowledge of the locality. As, however, it is not our intention to anticipate the decision of the Honourable Committee on the point, as to what kind of bridge is best adapted, feeling confident that they will lay this important point before our Diet for their decision, we shall proceed to consider the best manner of raising the necessary capital only, and for that purpose we shall assume that a permanent bridge can be erected between Buda and Pesth for the sum of 200,000*l.* If, now, the actual cost should be either less or more than this assumed sum, we consider it of little importance, since we are of opinion, that the success of the undertaking does not entirely depend on the accuracy of the estimates; on the contrary, we consider that it depends in a much greater degree on the good or bad choice of the sources from which the capital is to be drawn.

The practicability of raising 200,000*l.* in a country like Hungary,

no one can doubt, who has any knowledge of our resources. We shall, therefore, take the opportunity of pointing out to the honourable Committee the various ways in which it can be done.

First.—The sum named may be so apportioned to every inhabitant of the land, without distinction, as to leave the burden alike upon all, and oppressive to none. When the bridge is finished, every one may have the free use of it without toll. The kind of bridge we propose to build will cost but little in annual repair, and this may easily be paid by the State. Our object will be thus attained; the two cities become one, and the two portions of our territory separated by the Danube permanently united.

Whether the imposition of a new, though trifling burden, might not perhaps weigh too heavily on those who now pay taxes, and lead to others, is a question of itself. We frankly confess, that such a measure is hardly in accordance with the spirit of the times or the duties of the present Diet, whose object should be rather to alleviate than to impose burdens.

Secondly.—The nobility might take upon itself the whole charge of providing the 2,000,000 florins. This sum, exclusive of the cost of maintaining the bridge, which the nobility must also bear, would amount to little more than nine times the value of the "Coronation present;" and if spread over four or five years, (the time it would require to finish the work,) would not impose upon us a greater annual charge than twice the amount of the "Coronation present." We should thus complete our bridge; every one would have the free use of it; and the nobility, with the proud satisfaction of having themselves only to thank for that noble work, establish a new claim to the gratitude of their country. This would give strength to the aristocratic element in our constitution, and recall the early period of our history, when the nobility contributed more to their country's service than the people.

But this mode of proceeding has its objections. It supposes us, as it were, going back to old times, and forgetful of the measures necessary to our present condition, entering as we are upon the summer of our national existence.

For example, let us take the case of a nobleman living on the other side of the Danube, and unable, from his advanced age, to leave home. He is subjected to an annual call of 20 florins for five years. Would not he with justice exclaim, "I never leave my

house; I don't even go to Pesth to look after my law processes, for whether I go or not, if I am in the right, I gain, and if in the wrong, I lose; my corn I send to Kanizsa, my wool to Odenburg; the Pesth bridge is of no use to me. Upon what principle of liberty am I to pay 100 florins towards an object from which I derive not the slightest advantage?—I, indeed, who from the badness of the roads can scarcely reach the nearest market." What answer can we give him? "Will you enjoy all the blessings of our common country, and contribute nothing to her. Do you not see the vigour that it would impart to Hungary, the strength it would give to the Crown, to unite by a permanent passage-way across the Danube the disjointed parts of Buda Pesth and our land; how it would, by stimulating our nationality, lead to the development of all that is useful and great?"

We hardly think this answer would be sufficient; and therefore are forced altogether to reject this second mode of proceeding, viz., throwing the whole cost of the bridge upon the nobility.

The objection to the above plan is less striking in single instances, than it becomes when many such undertakings as the Pesth bridge are under consideration. We firmly believe, indeed we are fully convinced by the living testimony of other nations, that one patriotic undertaking leads to many others, and gives an irresistible impulse to a general spirit of improvement. In this way we may look forward to the regulation of the Danube, and to connecting it and other rivers with the sea; to the construction of a railway on the Louisen-strasse; to the draining of our marshes; intersecting our country with canals; throwing bridges over all our rivers; and converting Pesth into a port, which, by means of a canal communication with the Theiss, the largest steam-boats from Tokay, Semlin, Essek, Sisek, Vienna, and even Constantinople, may reach without difficulty or delay. But how is all this to be brought about? Ever and anon by voluntary offerings (*libera oblata*).

What, then, would our good old gentleman on the other side of the Danube say, were we to knock at his door twenty times a year for similar purposes? For the glory of our country, 20 florins for a bridge at Szegedin; for a Komâder canal, 30 florins; to give an impulse to our country's trade, 10 florins for a railway to Raab; and so on, *ad infinitum*. And, further, were we to include the

cost of maintaining these works, &c., would not then the good old gentleman above mentioned become more dissatisfied as our country grew prosperous and enterprising, and at last take to flight, to get away from voluntary offerings and a free country?

Desirous as we all are, worthy Committee, to be useful to our country, shall we be satisfied, if, in effecting the construction of one bridge, we do not at the same time prepare a moral bridge to lead us to the accomplishment of other similar objects? and shall we believe that our fellow-citizens, after building one bridge, will remain for centuries indolent and listless, ere they project any other undertaking? No, worthy Committee, this voluntary system, this *liberum oblatum*, is ill suited to our manly age. Some may, indeed, advocate it, who regard our prognostications of our country's prosperity as idle dreams; we ourselves think differently, and regard the *liberum oblatum* as a feeble lever to operate with in times like the present. We believe that we shall be doing a far greater service to our country than the erection of one or even ten bridges would be if we strive incessantly and with all our energy to carry out a system which, natural and simple, has been found to work well in other countries, and which, if adopted, would be of the same advantage to our own. Following out this system, in consequence of the tendency of the age to occupy itself with useful projects, we shall have the good fortune, not only to accomplish a vast deal by pick and spade, but we shall be able to do, what is equally advantageous, employ the active and restless spirits of the day, and economise time, which is the greatest of treasures.

This better system, which we recommend, is an issue of shares. We shall avoid by it pressure upon contributors, and the disagreeableness of finding out some plan, by which we can equally distribute among the inhabitants of the land without exception, the costs of erecting and maintaining the bridge, without warring against principle, or losing ourselves in theory. The injustice of compelling men to pay for what they do not use will be done away with, and the inconveniences, to call them by no worse a name, attendant on the collecting of voluntary offerings, avoided, as well as those anomalies, which, in the present enlightened century, do us Hungarians no honour.

Shares, however, will not be issued to produce loss, as, with few exceptions, every body will gain by them.

The present bridge of boats between Ofen and Pesth, which is used upon an average nine months in the year, yields, according to the data collected last spring, an annual income of 40,000 florins, and would, according to the calculations then made, yield 100,000 florins, supposing it to stand throughout the year, and all persons passing over it to pay the present rate of toll.

Now, however, were the permanent bridge to cost 2,000,000 florins, as we have assumed, neither the 40,000 florins nor the 100,000 florins income would suffice to induce shareholders to embark in the undertaking. It would require at least 160,000 florins income—120,000 for a 6 per cent. dividend, 40,000 to uphold the bridge.

With respect to the last expense, according to the answers of Messrs. Telford and Clark, it would seem that we have estimated it too high. We must bear in mind, however, that in England every one but Royalty pays toll—that the tolls are taken in a simple and inexpensive manner, and few persons required either for that purpose or to look after the bridge; that cleanliness is maintained by persons who consider themselves compensated by the sweepings of the bridge, and so costs nothing. All this is very different with us, and therefore we prefer putting the above charges too high rather than too low.

The next question is—How are we to get the 160,000 florins income? By quadrupling the present tariff to those who now pay? Possibly: but then we risk diverting men, merchandise, &c., into another road, as, for example, the one by Földvar or Waitzen; but were this not to happen, can anything be more unwise than to saddle an already sluggish and inanimate commerce with an additional load, and so impose upon our payers of taxes a new and onerous burden.

A tolerable bridge, and one suited to our requirements, will scarcely cost less than 2,000,000 florins, whence it follows, either that we must have no bridge at all, because a particular mode of obtaining the funds is unconstitutional, or we must all be compelled to pay toll alike.

As to the impossibility of establishing a general toll, from its being at variance with our constitution, we have no hesitation in saying that the whole difficulty arises from a misconception of the

true spirit of the constitution. If its principles are to exclude every, even the smallest, improvement, and not allow us to unite our two cities by a bridge, when the project is to be carried out by means of shares, but compels us, by disproportionate burdens on the people, to attain our object; or to trust to the contributions of some hundred noblemen or so, in order that a few may be exempt from toll; or, otherwise, that the many who remain at home, and never use a thing, shall pay for the few who enjoy the full benefit of it: what is this, but a mockery of liberty?

Had our constitution depended for its stability on such wrong-headed notions as these, it never would have lasted so long, or had fate hitherto preserved it as a phenomenon, in the present day it would have instantaneously perished. Of this we have no fear. We maintain that the erection of the noblest national monument, by means of shares, is in perfect keeping with its true philosophic spirit. Prejudices in direct opposition to this have prevented us accomplishing any one great thing. It is quite impossible to construct and sustain great undertakings in the two ways above mentioned, of which fact our country affords us sad proof, in not having one single work of public importance to show. The error lies, not in our constitution, but in the wrong notions entertained of our constitution, and these keep our country in bonds. Further, we beg to ask, how it can be considered contrary to the spirit of our constitution, if on any day of the meeting of the Diet, of our own free will and common consent—in short, under no restraint whatever—we pass a law of exception, that for a definite time, every person, without distinction, noble or otherwise, shall pay a certain toll to be fixed by the Diet, in passing over the new bridge between Buda and Pesth: but we shall by and by refer to this subject. We ask now, how can our liberty be encroached upon by such a law? would a constitution be called free which was averse to such a law? would it merit our support? Could the Hungarian respect a law-book, wherein was written, "Thou shalt not build a bridge by means of shares; Thou shalt not improve the navigation of the Danube?" that is, "for the strict upholding of thy liberty, thou must remain where thou art, and never deviate from thine old ways;" still more, "Thou shalt not alter or amend that law, which to thy greatest injury excludes thee from the payment of toll, for the purpose of promoting national undertakings."

Here, as everywhere, the multitude is led into error from its inability to make proper distinctions. Were the government without any previous law to build a bridge and impose a toll, however small, we might have our fears and anxieties; we had rather, perhaps be deprived of any bridge in future, and pass the river in boats, even in winter, however inconvenient it might be, than pay for a bridge built by any but ourselves. The ice would be preferable to a tax imposed by a foreign hand, which being arbitrarily imposed, might, we fear, become intolerably oppressive, so that the "nothing" would be far better. But let us ourselves name the burden, and the Diet regulate the tariff for the future—what danger can we then apprehend? Can resolutions of the Diet, which concern our internal welfare, at all alarm us? Those laws and ordinances, which impose equal burdens, and, for a limited time only, upon the inhabitants of a land, are the surest triumphs of liberty, and evince the true vitality of a nation. It is a *sine quâ non* that all share the burden alike, or otherwise we shall fall into the unavoidable dilemma either of pressing too severely on one particular class, or of abstaining from a great national undertaking, because of its incompatibility with our notions of liberty. This error is the cause why we Hungarians, in perversely adhering to our independence, have no other than frail and perishable monuments to show. Were each person, however, to share the burden of the work, which the nation contemplates, no one would feel it more than another, and there would be no undertaking hereafter that we might not project, and successfully carry out. Laws, which aim at nothing but the national welfare and the national glory, can never be thought oppressive by any true patriot, provided they are enacted for a definite time only, *i.e.*, in the present case, provided the payment of toll is to cease in a certain number of years. Now, unless a profit can be shown, no shares will be disposed of. If, in future, those only are to pay toll who now pay it, the shareholders will gain nothing, nay, rather, they will lose, for a fixed bridge will not cost less than 2,000,000 florins. We shall then find ourselves reduced to the painful dilemma either of increasing the toll four or five fold to its present payers, or of having no good and permanent bridge. Thus, from our mistaken notions of liberty, we shall in future have to contend with water and ice, transport ourselves and wagons in sledges over

the ice, and submit to numerous other inconveniences—a pretty caricature of liberty!!

The hope, which many entertain, that the shares will easily be disposed of, though offering only two or three per cent. interest, is a pure delusion, and entirely nullified by the incontestable evidence of figures.

Suppose the bridge to cost 2,000,000 florins, keeping it up, 40,000 florins, rate of toll as at present, there will remain for payment of interest on 2,000,000 florins the income of the three winter months, during which the bridge of boats is removed. This income we estimate at 20,000 florins; hence, instead of two or three per cent., the shareholders will scarcely get one per cent., and there will not remain a kreutzer for a sinking fund. For such a speculation we do not believe we shall get 2,000,000 florins. No one—least of all, we Hungarians—can afford to throw away such large sums, needing them, as we do, for so many other purposes. Let us build our bridge "by shares!" "by shares!" as many cry out; but this is not the true bearing of the case; the compelling our nobility to pay toll is the real point.

"We must build a good bridge cheaper, then," exclaim persons. We are not of that opinion. The English and the Americans have never yet found out how to combine cheapness with goodness in the construction of their bridges. Whether we, with our scanty means and small experience, shall be more fortunate in effecting this desideratum than those who have had the multiplied experience of some hundreds of bridges, which now stand, and firmly stand, is a question we are not prepared to decide; but this we say, that in our judgment, we shall act far more prudently in making up our minds at once to an outlay of 2,000,000 florins, than in spending as much, or probably more, in experiments: for in the one case we shall undoubtedly have a good and useful thing for our money; and in the other, most likely fail in our experiments, and lose both money and time.

The whole matter reduces itself to a question, whether the country will rest satisfied with its present communication between Ofen and Pesth or not. If satisfied, the present mode of meeting the expenses of the bridge is perhaps suitable enough, and things may remain as they are; if not satisfied, a greater number of

participators in the expense than now will be required. Without contradiction and manifest anomaly, there is no mean between these two alternatives. Where are we to look for these additional participators, but in our own country? We ought therefore to encourage that principle of justice which teaches us to take on our own body new and great burdens, for new and great objects, proposed and carried of our own free will and common consent. This principle is not only in accordance with the true spirit of our constitution, but, in proportion to its development, the surest and firmest foundation of true liberty. The recognition and application of this principle is not only a *conditio sine quâ non* towards the erection of a more expensive bridge, but also towards putting beyond doubt the practicability of any undertaking that shows a profit. Were we to succeed in building our bridge as we propose, and were it to return less interest than we anticipate, the principle once established, we should have no difficulty in applying it. In a few years, in a country like ours, capable of so much improvement, we should see such great and stupendous works carried into effect as would surprise and astonish even those who now look sanguinely to the future. Of this, we have a striking example in America—a thinly-populated country—where a hundred times more has been done in one century, than in Hungary during a thousand years.

Let us return to our bridge. We come to the conclusion, that we must adopt one or other of the plans mentioned, or have recourse to the share system, and compel every one, without exception, to pay toll. The toll must be increased, in order that the income of the bridge may meet the interest required, the cost of upholding it, and leave a sufficient sum to establish a sinking fund for the gradual repayment of capital, and for throwing open the bridge to the public, after a certain period, toll free.

We think we have sufficiently shown the inappropriateness and objectionable nature of the first and second schemes, and hope our third proposal will meet with favour and support; since the greater number of our fellow-citizens are prepared to take upon themselves "for new and great conveniences, new and greater burdens." The success of useful undertakings must of necessity follow, when the greater number are agreed as to the manner in which the burdens are to be shared. These, if imposed in the two ways previously mentioned, would be repulsive, unjust and complicated; whereas,

if imposed in the third way, they would be just, natural, and simple.

We must either renounce our bridge and every other great undertaking, or pay toll of some kind for a definite period. The payment of toll is however so detested among us, that we scarcely hope to triumph over the prejudice against it; but let us try. In what this horror of toll-paying originates we will not inquire, as it would carry us beyond the limits of our report. England and the United States, where freemen dwell, and pay self-imposed tolls, are sufficient for our example. May we ask, why the temporary payment of bridge-toll deserves such opposition, that we must forego all the advantages which the connecting our two cities would confer upon the whole land and our national existence. Let us now be allowed to show the practical part of the matter, *i.e.*, the little difficulty with which the mechanism of toll-taking can be conducted.

First of all, the tariff of our bridge must be so arranged and established by the Diet, that the probable income may amount to 200,000 florins. This sum may, according to our calculations, be obtained by raising the existing tariff to "Convention's money," and making every one, without exception, pay toll.

In this way 5 per cent. interest will be covered by 100,000 florins, the cost of keeping up the bridge by 40,000 florins, and a clear 60,000 florins remain the first year for redemption of shares. In proportion to the increase of this last sum, the fundamental capital will decrease; a less and less sum for interest will be required, and more shares constantly paid off, so that in about 20 years the bridge will have paid itself, and may be thrown open toll free to every one, leaving an annual charge of 20,000 florins to sustain the bridge and keep it in good repair. This sum may be obtained in various ways: by charging a certain toll for horned beasts, putting a window-tax on all householders of the two cities, or perhaps by allowing the payment of toll to last for 25 instead of 20 years. This last expedient would yield a clear sum of 800,000 florins, thus constituting a capital for the 40,000 florins which will be required for keeping up the bridge.

To avoid the inconvenience of always putting one's hand in one's pocket to pull out a silver kreutzer to pay the toll, subscriptions for a certain time might be allowed; and thus the necessity

obviated of presenting a ticket. The toll-takers would soon know the subscribers. If we compare with this all the disagreeables we have in winter to submit to, we believe no one can make any reasonable objection to the payment of bridge-toll, especially when either the "this or that" occurs to him, upon which the whole matter turns, viz., that a bridge is impossible unless every one pays.

But notwithstanding all the advantages which attach to the third plan, we must confess to the Committee, with the same frankness that the Committee itself owes to the country, that, in our opinion, the success of the bridge will not be assured by a creation of shares, although every one without exception is made to pay an increased toll. The entire affair must be intrusted to a Company, which must have the right of levying a certain toll upon every one who passes over the bridge, and be protected by the state against every possible damage and injury.

Further, if we take for granted that the Diet passes a law, for a limited number of years, to subject every one, without exception, that uses the bridge to pay the toll, and grants the Company which it takes under its protection, the requisite privileges, shall we consider our triumph complete? By no means; for the Company must first appropriate its 20,000 shares, *i.e.*, obtain its 2,000,000 florins. This is a great difficulty, which it is better to remove at once than, after much trouble and contention, gain a point and subsequently abandon it. Two million florins is a large sum of money; it is required, however, for our 20,000 shares; but where and how shall we dispose of them? In Hungary it is difficult to believe; we may succeed, indeed, to the extent of a few thousand florins, but where are the 2,000,000 to come from? Perhaps they may be taken on the Continent. Our credit, however, abroad stands very low. Perhaps they may be taken in England? Not at all likely; bridges there have been such bad speculations that nobody would touch them. This is no argument, however, against our bridge, because English bridges are so numerous, and have been constructed at so great an expense, that they yield no more than one or two per cent. profit.

In England the dividend is less regarded than the usefulness and advantage of safe and permanent communications. Several bridges, as the Waterloo, Southwark, &c., have comparatively little traffic, and return scarcely any profit, and may be considered as

mere objects of which the nation may be justly proud. In England probably not one of our shares will be taken, although our bridge may be considered in quite a different light to any other, being the leading point of communication for the whole country, as well as for the two main cities. Nor will its income be precarious, but absolutely certain; so certain, that we know of no safer investment for money, either in an industrial or mechanical point of view, than the shares of the Pesth and Ofen bridge.

But perhaps this is our conviction only, or that of few, and not enough to secure success to our undertaking; for although we few are willing to contribute according to our means, our contributions would barely pay the interest on the 2,000,000 florins, whatever might be our inclination. The magnitude of the sum demands the co-operation of large capitalists, few of whom are to be found amongst us, and enough has been said to disabuse us of reliance on foreign countries.

Besides all this, one circumstance, which makes us doubt whether 2,000,000 florins can be realised for a Pesth and Ofen bridge, must not be overlooked. It is a general rule, that the rate of interest rises or falls in exact proportion to the soundness or unsoundness of the security. Let the public, or those who possess the 2,000,000, once be convinced of this, and the building of our bridge is certain. We cannot conceal from ourselves the little confidence the public has in a work like the Pesth bridge to stake its money in it at five per cent. However, this may in some measure be remedied when we consider the nature of interest. The shares, it is clear, will only be taken by those that like them. Now, if there be any law limiting the rate of interest, nobody will take one. If, however, the interest is left to itself, instead of 5 per cent., the shares will bear 6 or 7 per cent.; and as the annual drawings proceed, instead of the shares selling for 100 florins only, they may bring 120 florins, perhaps 150 florins. The whole affair would thus wear another aspect, and many, attracted by the safe interest and possible gain of 20 or 50 per cent., would invest a portion of their capital in our bridge. But, honourable Committee, speaking frankly, is not all this extremely problematical? and should we discharge our duties as we ought, were we to persuade our countrymen into an undertaking of whose practicability we were doubtful? the more so that we, the representatives of our

country, after repeated discussions and entire publicity, had passed a law which could have no good result. Could we ever forgive ourselves for having so compromised our country? and would it not have been far better not to have agitated a matter that could only mislead and embarrass us, and could not be carried out? Although we agree with many in respect to the money part of the business, who, with cash at their command, are as competent judges in their way, though not more so, than Messrs. Telford and Clark of the mechanical part of the business; and although we are assured by them that money enough may be found, and the Pesth bridge built by shares in the manner proposed, we consider it only probable, but not certain. One may reason much on such matters, and there are not wanting persons who, easily lending themselves to delusions, become at once silent and cautious, and draw back immediately—it is a question of deeds, and not of words. We, however, are responsible, and must struggle for success; and therefore, honourable Committee, since for other enterprises, such as canals, steamboats, &c., which have a sure foundation, and inspire the public with more confidence, we hold the system of creating capital by shares to be all-powerful, we prefer this way of building a bridge. Though it is not an undertaking which enjoys general favour, in our opinion it is the surest method, and so certain to succeed, that we shall not risk the reputation of the Committee, nor compromise the representatives of our country, nor disappoint the general expectation, but, by God's help, we will greet the four quarters of the land with a permanent Pesth and Ofen bridge.

This method is so safe and simple, when properly understood, that it cannot fail to meet with general approval. It is the same by which the United States, in spite of its surprising extent of territory and small population, has achieved works that appear as phenomena hitherto unknown, excite the astonishment of the world, and never could have been produced in such perfection and in such numbers if the system had not been sound and good—a system which constitutes the soul of industrial, mercantile, and political enterprise, viz., the Bank system.

Thus, as far as money is concerned, your honourable Committee will find no difficulty in the construction of a bridge. Let us examine the matter.

We have already said that a permanent bridge between Pesth and Ofen will produce an annual income of 200,000 florins, if every one without exception were to pay a toll in silver money. This granted, we should have no occasion to borrow or beg. We should have simply to issue 20,000 Hungarian national bonds, of 100 florins each, to make up the 2,000,000 capital, put this paper money under the protection of the state, and after paying on it 5 or 6 per cent. interest, redeem it by an annual drawing. In this manner the bridge may be built without costing any one a kreutzer. Those only who use it will gradually and insensibly pay for it, our two cities and territory be connected, and the 2,000,000 after a certain time be paid off.

A sufficient fund may in time be obtained for the annual cost of upholding the bridge; after that the bridge may be thrown open to the public toll free; or should it be the wish of the country to continue the toll, a means may thereby be afforded to us of embellishing our two cities, and by good regulations so cleansing and purifying them, that they may rank among the first cities in Europe. By the payment of a kreutzer each time of passing the bridge, or by an annual subscription of a few florins, we should gradually see the erection of buildings and monuments that would incessantly excite our admiration and astonishment, and we should be able to boast of having achieved so much of the useful, agreeable, and ornamental, with comparatively little inconvenience or burden; we should learn to co-operate and unite for practical purposes, and we should become better acquainted with our strength and resources, which neither the floods of the Danube, nor the mountain heights around us, nor anything else, could resist.

We well know, honourable Committee, that this our project will at first produce no favourable impression on the public, but we shall not the less recommend this course to your notice, resting assured that it will ultimately be approved of and adopted.

The first objection we shall hear will be, "What a pity to issue paper money, incur national obligations, tarnish the halo which has hitherto encircled us, of being debt free!"—"Our laws recognise gold and silver money only." Our answer is easy.

Inasmuch as the value of gold and silver does not surpass that of iron, is perhaps even inferior to it, but owes its appreciation to its durability and scarcity, and is therefore received among nations as

a good representant of commodities; in the same way, paper money, though possessing no intrinsic value, may represent any amount of gold and silver, according as it is based on good or bad security. Water itself may destroy life, yet there is no living without water. Fire, our best benefactor, may become our fiercest enemy. Medicine may kill as well as cure, and the knife which cuts our bread become an instrument of murder; even so the issuing of paper money and the incurring of debts turn to our greatest benefit or harm. The conclusion we naturally arrive at is, that the benefit to result from things depends upon the use made of them, and that we have it in our own power to remedy the evils of paper money and loans, and by a right use of them to promote the prosperity of our country.

Were we to build the bridge with our own paper money, in twenty or thirty years at most the whole sum would be obtained from the income of the bridge, and no debt remain. Would then our conduct be blamed, and should we be reproached with having injured our country? We think not; for, as in trade and industry it is dangerous and detrimental to incur debts from extravagance, it is, on the other hand, a proof of extraordinary short-sightedness and want of judgment not to borrow, when there is clear and certain gain; in other words, it is folly when money yields only 3 per cent. to raise it at 5 per cent., and thereby incur an actual loss of 2 per cent., which in time would infallibly eat up the capital. The reverse is equally absurd; viz., not to borrow at 5 per cent., with the undeniable certainty of making 8 per cent.; for as, in the first case, there would be a certain loss, in the second, the capital would as certainly be redeemed.

If this is actually the case, can we any longer doubt that it is prudent and wise in the nation to pass a law for the issuing of 2,000,000 florins national bonds, for the erection of a Pesth and Ofen bridge? Provided—1st, That its construction does not exceed 2,000,000 florins. 2nd, That it produces an annual income of 200,000 florins. 3rd, That the annual expenses do not exceed 40,000 florins.

The money which the country borrows at 5 per cent. will, strictly speaking, produce 8 per cent., and therefore there will be a clear gain of 60,000 florins annually, which may be appropriated to cancelling the debt, or any other purposes that may be thought fit.

We trust we have shown how trifling the objection to paper money is, and how foolish and impolitic it is to abstain from borrowing money and incurring liabilities in certain cases, as it is to borrow and get into debt in every case. Suppose, for example, a man had an opportunity of buying an estate that would return him 8 per cent at once, and was capable of great improvement, would he act wisely in not buying it, provided he could find the purchase money for 20 or 30 years at 5 per cent., or for as long a period as would be necessary to cancel the debt out of the surplus of his profits? Should we not consider him a fool to decline such a purchase? What shall we then say of a nation, honourable Committee, whose main prosperity depends on its industry and a thriving commerce, whose soil admits of immense and endless improvement, and which wants only capital for the development of its resources? What shall we say of this nation, if it be so prejudiced that it will not borrow money at 5, which will return 8 per cent.? What, but that it has neither energy nor enterprise. Let us trust, then, boldly to the spirit of truth, which will sooner or later, but infallibly, teach the inhabitants of our dear country the art of working wonders in poor and unpopulous countries, by means of the system we have been advocating—the Bank system.

If national bonds of 100 florins are issued to the amount of 2,000,000 florins, it is the same as if the country had borrowed this sum, but with this difference, to which we call particular attention, viz., that the nation is its own debtor. Interest at 5 per cent. on the above capital will cost the country 100,000 florins annually; if, therefore, the bridge return an income of 160,000 florins, exclusive of keeping it in repair, the country will then have its bridge, and all the benefits, direct and collateral, belonging to it, and be a gainer of 60,000 florins besides. We therefore strongly recommend our plan to the honourable Committee and to the representatives of our country—a plan which, for industrial and commercial undertakings, no person would disapprove, and a nation ought not to reject. And why not? Simply because the creation of a Pesth and Ofen bridge is of little consequence compared to the establishment of our Bank system, which would originate endless improvements, and enable us to accomplish the greatest works, converting our land, in the course of time, into a paradise. So long as man is man, only make it clear to him that his interest

and advantage are involved in an undertaking, and he will achieve things almost impossible. Building our bridge in the way we propose, will offer a useful and valuable guide to us on future occasions, when greater works and larger profits are in contemplation.

How many projects does not our country offer, which would return 18, 20, or even 50 per cent.? Who doubts that want of money is the cause why our rivers are neglected, our marshes undrained, our means of communication few and bad? If these be facts, and they are undeniable, would it not be wise in a nation to borrow money, at a moderate interest, and drain its marshes, when a large per-centage might be gained thereby?. But between a nation and a private individual there is a difference; a man cannot be his own debtor; and such operations as improving the Danube, draining and restraining the Hanság, the Sarrét, &c., exceed his means; whereas a nation may be its own debtor, having greater resources at its command, and be safe against the debt being called in. Who are we to look to, if not to the nation, for the improvement of our numerous rivers, and for the recovery of vast tracts of useful land?

Although, in certain cases, it is well and prudent to borrow money, as a general rule it is dangerous to do so. The facility of obtaining is apt to seduce us into extravagant and hazardous undertakings, which, when carried into execution, prove ruinous and unprofitable. We think it highly objectionable to borrow money imprudently; but are we never to borrow for really profitable purposes? buy nothing whatever without first having the purchase money in our pockets? that is, if we may be allowed the illustration, are we never to use a knife, for fear of cutting our fingers; or fire in our hearth, for fear of being burned? All things depend on the use made of them; the same thing may, in good or bad hands, be a blessing or a curse.

The objection we have considered is untenable; but we fully admit the dângers to which the borrowing of money exposes individuals, who are easily influenced by their passions and weaknesses, and, blinded by hope, fall victims to delusions. A legislative body, composed as it is of heterogeneous elements, is less easily led astray; its deliberate and cautious movements give time for the extinction of those false hopes and empty illusions,

which might be dangerous, if unchecked. The Bank assignats of France, and the enormous debt of England, are fearful examples against the issue of paper money. But, Honourable Committee, there is a very striking difference, and one we cannot lay too much to heart, between our case and theirs, which, independently of the consideration that the French paper of former days and the present English paper must be regarded in a totally different point of view, (a matter we shall not now enter into,) shows quite clearly that the Bank system, now advocated, cannot fail to be as beneficial to us as it was formerly to the United States. It by no means follows that it must be applicable to France and England, but merely that the benefits of such a system must depend entirely upon circumstances, or rather upon the condition of a country. And, in truth, where improvements afford a profit of 20, 30, and 100 per cent, as is often the case in America and Hungary, paper money answers exceedingly well, as the debt is sure of being cancelled; but where, as in England and France, no such profitable undertakings are possible, the system is inappropriate and may do harm. A calculation was lately made, that the cost of a Danube embankment, in the county of Pesth, by which 400,000 acres of arable land would be obtained, would come to about 700,000 florins, C. M. An acre of land, which, in many parts of the county of Pesth, lets for 2 florins per annum, would cost only 1 fl. 45 kr. Thus this embankment would not only repay in one year the capital expended, but bring in some hundreds of thousands of florins annual rent, and so pay an enormous per centage on the original outlay.

Does not this palpable example of immense profits teach us that, as it would be inexcusable if the parties interested did not, by every possible means, procure the sum of 700,000 florins, and carry out this advantageous project, it would be quite as inexcusable, and gross carelessness, in a representative body of the year 1833, if it did not legalise certain sums for such remunerative undertakings as a Danube embankment? and who can doubt that, by and by, numerous similar works will be met with here, as in America, for the completion of which, not merely 700,000 florins, but several millions will be required; and which, while these millions are not forthcoming, must either be abandoned altogether, or gradually carried out by the issue of paper money from time to time. The substance of what we have said is this, that, as it would

be lamentable folly to create money without mature deliberation and sound calculation, and so lead ultimately to ruin; it would, on the other hand, be an intolerable grievance to pine away among unhealthy marshes, be eternally without communications, and obstinately sacrifice to paltry and wretched prejudices all national impulse or development.

Our country is capable of endless improvements! Let us only adopt this grand system, so especially suited to us, and nothing will be impracticable: if we reject it, we shall have to renounce all that is dearest to us, all that will, in reality, exalt our country, and, by degrees, make the Hungarian rank among great nations. Unless all parties do their best for the internal development of their country, unless we venture to adopt the means already proposed for our benefit and advantage, we must not once dream of all that which would satisfy our wishes, and present the spectacle of a well-developed national character; or, if we resign ourselves to such dreams, we shall find, when we awake, that we have been grievously deceived.

The Committee will perceive, from what we have here advanced, that, in our anxiety for the mechanical part of the bridge, we have not merely had in view the easier passage from one bank of the Danube to the other, but contended for a far more important advantage, a moral one, viz., the good that must necessarily accrue to other similar undertakings from the solid and practical conclusion of one great work. If it can be shown by facts, that works like the Pesth and Ofen Bridge, offering only 3 per cent., can be successfully carried out by a system, whose two leading principles are the imposition of a general and equal tax upon all inhabitants of the country, and the anticipation of a sure profit; as a matter of course all those operations which yield 4, 10, 50, per cent. will quickly follow. How many of these treasures lie hidden in our land, which, so to say, await only our turning to account that they may become the firmest supports of our country and the throne, and fortify the nation against all chances and accidents, who that knows anything of Hungary can for a moment doubt?

This collateral purpose, we might almost call it this principal one, we consider ourselves fortunate in being able to bring forward, as it gives us an opportunity of setting forth, in its main features, a

system which has borne the test of experience, and at once overthrows all the objections which have been advanced against our patriotic undertaking; such as "What is the use of a bridge, unless you have good roads? "Let these in the first instance be attended to." "Why build a bridge, before you have regulated the Danube?" "Of what good can a bridge be to us, with a trade so borne down by heavy duties in foreign countries that it can never prosper?" To such objections we can only give a brief answer, or our report would swell into volumes. The Pesth and Ofen Bridge will be less useful to us as a mechanical structure, than for its moral effect in encouraging the practical carrying out of a grand system. Though the profit be only 3 per cent., it will be far more serviceable than any other undertaking, however profitable. Now that the Diet is summoned to meet by one of the best of Princes, there is no one object that unites so many voices in its favour as the building of a bridge to unite our two cities. Every inhabitant of Pesth and Ofen cherishes the wish, a few wiseacres and egotists only excepted; every citizen of our land, who looks beyond the next day, desires it; indeed, the spirit of the times absolutely demands it, and will no longer tolerate the division of our territory by a river.

The positive erection of the bridge by this means will convince many that neither gold nor silver is the basis of a nation's wealth, but that development of human intelligence which, having profit and interest in view, leads to the discovery of some preliminary instrument, by the proper application of which the most gigantic projects may be achieved. The everyday silly talk of "wanting money and means," to which we particularly ascribe our country's backwardness, (mechanically speaking,) is difficult to remedy, because most persons consider that an impulse to prosperity can only be given to it by an inanimate white or yellow metal, which for many thousand years, perhaps, has been lying in masses on the surface of the ground in South America, without having raised its inhabitants nearer to a condition becoming humanity; a condition not to be acquired by gold and silver, but by that mental energy alone, which is inherent in us, and constitutes our immortal part. It is this power which teaches us to reflect, which, according to our condition in life, rouses us to a consciousness of our wants, which stimulates us to industry and activity, imparts a

charm to our existence, and, by exalting our animal condition, converts our dwelling-place into an Eden.

The establishment of a National Bank, now only advocated by a few, will become a general wish, and eventually be realised. The halo of credit, which some, to the prejudice of our national faith, have so shamefully tarnished, will, in some measure, be *de facto* restored, even before the mechanism of our national credit be perfectly in order. It will become clear, that as shares and a Bank system are best adapted to profitable undertakings, there are, nevertheless, others—such as Bridges, Theatres, Museums, Polytechnic Institutions, Institutions for the Fine Arts, &c., offering no other than an intellectual dividend—to which a banking system would be of no direct advantage, and only so far indirectly contribute, that in making our countrymen rich, it would enlist their good deeds as well as good wishes, and enable them to promote all such useful objects. Hungary, a country now comparatively unknown, will soon take its place among polite nations, the success of one great work will operate beneficially towards the achievement of many others, which it is impossible to foresee; so that the mechanical connection of our two cities and our territory may form but a small part of the good which will result.

What importance, then, shall we attach to the objections of those modest reasoners, who are incapable of embracing the real point of the case, and argue thus—"Why so very costly a bridge? that the inhabitants of the two cities may pay visits with greater convenience?" Besides, we have our bridge in summer, and oftentimes in winter the Danube does not freeze; why not, therefore, let us have something else?"

It rests with the Honourable Committee to decide what weight is to be attached to these objections and remarks, when the philosophy of the matter against which they are directed is considered, and also what value they have when brought against our plan. Our want of space will not admit of our refuting them.

We cannot, however, leave unnoticed the "Memoir of Alexander Györi, upon a permanent Bridge between Pesth and Ofen," which has just appeared. It contains a great deal that is good and acceptable; but, in our opinion, it would not be advisable, for two reasons, to adopt his preliminary proposal and assume his premises.

First, because the mortgage for the money, with which our honoured countryman proposes to build his bridge, is a very poor one. His calculation is, that the building ground ultimately to be gained from the river, and now constituting a portion of its bed, will be worth 54 florins, C. M., per square klafter. This undoubtedly will be its value in a few years, for both cities will progress equally; but whether now, or by and by, purchasers enough at this price will be found for ground which is liable to be flooded by the Danube, is now in possession of that river at low water, and has been so for centuries, we may be allowed to doubt. Secondly, because his proposal leads to delay, and delay, in our country especially, is fatal.

The remarks in the pamphlet, "that no safe and permanent bridge is practicable before the Danube is regulated and improved," are controverted in all parts of the world; for how many bridges are there not over rivers whose waters are unrestrained? and in what condition would the communications in the United States be, if the rivers had first to be regulated before a bridge could be built? Were, however, the views of Herr Györi incontrovertible, what more do they prove than the impossibility of building a bridge over the present bed of the Danube which shall last for ever; and that the bed of the current must be kept constantly clean, to prevent the piers in it from being undermined? Suppose they prove nothing more, why then shall we postpone the matter, and delay, probably for centuries, a work which will be of incalculable benefit to us, pay itself in thirty years, and then be thrown open toll-free to the country. There would be no reason then against commencing it forthwith, were we positively certain that it would be destroyed in thirty years, whilst the indirect good it would effect would not be lost to us. And is, then, our Danube so irregular and raging a stream, that no bridge can be built over it which will last more than thirty years? Herr Györi himself is not of this opinion, especially if the bed of the river be kept constantly clean by proper machinery. Herr Györi's proposition might be very well, were this true; but the nation's business is to build a bridge without delay, which, well secured, shall last for centuries. At the same time, it ought to take steps for the regulation of the Danube. It is quite certain, that the nation will not only be a gainer of the 3,900,000 florins promised by Herr Györi, but will have effected,

mechanically and morally speaking, a change in the country that may be designated as a new era in the regeneration of Hunnyad.

We must also notice the important observation relative to the two millions of our national paper money, maintaining its true value or not, *i. e.*, whether the 100 florin bonds may not probably fall to 80 or 90. We answer, that the value of the bonds to be issued will infallibly be maintained in proportion to the security or insecurity of the mortgage. If the mortgage is good, or the public considers it so, and if the interest is regularly paid, and the bonds redeemed by lot at 120 or 150 florins, then may we hope, that our bonds will not only be at par, but rise considerably above it. The bridge itself will serve as the mortgage, and can easily be assured, if not entirely, yet with respect to the ironwork; and in no case will there be any great danger to apprehend. But, in order to quiet the public at large, and raise the price of our paper money, it would be as well, if only for the credit of the thing, for in all other respects it would be unnecessary, to have another mortgage besides the bridge. For this latter purpose we think nothing so good as the high salt tax, if Government will agree. The security would then be perfect. We may reasonably hope we shall have no difficulty with the Government, as the favour would be no greater than that which a man would confer were he to give his creditors priority of claim to his house or grounds, by which perfect security for the capital would be obtained without the house or grounds being actually given up.

Lastly, we must declare our honest opinion on those observations relative to the Government counteracting our efforts. We do not think it at all likely the Government will thwart a system so advantageous, which hurts nobody, but makes use of the treasures concealed in the bosom of rude nature to promote the interests and prosperity of a country, which constitutes the best security of the Austrian monarchy. Where there is a will, there is a way; and, therefore, the Government, whose manifest interests are allied to the greatest possible augmentation of the means and contributions of Hungary, the improvement of our communications, the regulation of our waters, the development of our mechanical industry, will throw no obstacles in our way, but do its best to promote all such objects; in short, it will do all in its power to increase our wealth, to multiply our resources and strength, and to promote the general

welfare and general contentment, which have ever been and ever will be the surest supports of a throne.

The adoption of a good system, in building a bridge between Pesth and Ofen, will, as we have already said, conduce to the prosperity of our material industry, diffuse employment, and lead to consequent contentment. It is not in the least probable that the Government will throw impediments in the way; on the contrary, we expect to find in the Government our firmest supporters.

And here, Honourable Committee, we close the political part of our recommendation; and, without inconveniently lengthening our Report, we will beg to add a few words on the practical carrying out of the undertaking.

Before all things we must avoid entrusting the superintendence of the work to a person who has never been engaged in a similar undertaking: neither testimonials, calculations, nor promises must be admitted under any pretext whatever, but a good builder must be chosen, who has given proofs of his capacity by the great works which he has executed standing in full indestructibility. This matter settled—and of the propriety of doing it in the above way no one can doubt, who calls to mind the many undertakings with us that have entirely failed from having been constructed by mere theorists—we must look to England or the United States for the artists we require, for there only, and no where else, are to be found works, where the difficulty of accomplishment is about equal to the complexity of the problem, which the construction of a Pesth and Ofen bridge has to solve.

And if this be the case, Honourable Committee, we shall take the opportunity, when the subject is brought before the supporters of our Committee, his Highness the Palatine, and the Diet, of requesting that a "Regalist" deputation be appointed, to digest, arrange, and subject to the strictest investigation our diffuse information and data; and at the same time that competent persons be sent abroad to enquire more minutely into matters which we have but superficially and partially handled.

Our Report is wanting in many respects; our calculations may be erroneous; certain fundamental questions, such as the revenue of the present bridge of boats, we have hardly touched upon; we have been unable to say anything positive about the insurance of the bridge; numerous subordinate considerations we have not even

mentioned; and the more we weigh the matter, the more evident it is to us that we have done little for it, and must renounce all hopes of its being executed, unless the Honourable Committee supports the undertaking by its powerful influence with the States of the Land, who alone are able to do it, and, in our humble opinion, would in no way compromise themselves were they at once to pronounce their creative "fiat."

This single word, which would diffuse over our territory the greatest benefits, would not only reward us a thousandfold for all our pains, but would bind us in an eternal debt of gratitude for the remainder of our lives.

Commending ourselves to the favour and indulgence of the Honourable Committee, we remain

The Honourable Committee's

Most obedient Servants,

GRAF GEORG ANDRÁSY,
GRAF STEPHAN SZÉCHENYI.

MEMOIR OF COUNT SZÉCHENYI.

FROM PAGET'S "HUNGARY AND TRANSYLVANIA." 1839.

COUNT SZÉCHENYI ISTVÁN, is the third son of the founder and benefactor of the Museum of Pesth—a scion of the same house which produced two of the most distinguished archbishops of Hungary. For seventeen years Széchenyi served in the Austrian army, and it was not until the peace had rendered it an idle life, and removed all chance of distinction, that he determined to quit it. Perhaps, disgusted by the system of favouritism, or the personal enmity which had kept him down to the rank of Captain; perhaps moved by that spirit of regeneration, which, from the mountains of Transylvania, spread over the plains of Hungary, and was felt even at the gates of Vienna itself; or, it may be, warned that the freedom with which he had dared, under the influence of this spirit, in his place as a Hungarian magnate, to address the Upper Chamber, was inconsistent with the uniform he wore; such have been suggested as the causes which may have driven him from the army, and which soon placed him in the foremost rank of Hungarian patriots.

The leisure which he now enjoyed was occupied in foreign travel; England particularly fixed his notice. Our manners, our institutions, our commerce, were objects of his study, and offered him useful hints for the improvement of his native land.

The causes which impeded the introduction of commerce in Hungary, and the great development of her natural resources which must result from their removal, first occupied his attention. At home, he found a government and people, mutually distrustful.

The Hungarians complained to him that foreign—so they called Austrian jealousy and oppression — were the sole causes of all their misfortunes, while, beyond the Carpathians, he heard his countrymen described as a tyrannical, ignorant, and turbulent nobility; the oppressors of a poor, idle, and slavish peasantry—the one class who would not, the other class who could not, effect anything for the common advantage of their country. On all sides a reform in Hungary was declared impossible.

Széchenyi was not to be turned from his object. His plan was cautiously laid down, and has been, so far, steadily followed up: to labour incessantly at improvements, and to pursue such only as the strength of his means gave him a reasonable hope, that, with unwearied perseverance, he might carry through. In common with others, he had always striven for the great objects of reform in the laws and institutions of the country; an extension of the rights of the lower classes, and a more equitable and just government. But his great and peculiar glory is the path he has marked out, alone, and which, in spite of all obstacles, he still pursues with the greatest success, viz.: the improvement of the material condition of Hungary. One of the first objects to which Széchenyi drew the attention of his countrymen, was the improvement of the breed of horses—a subject particularly suited to their tastes, and likely to attract their notice. A large stud, often from one to two hundred horses, forms almost a necessary part of a nobleman's establishment, and yet they rarely breed anything but a cross of the common country horse, with the large, slow, high-actioned Spanish horse—a race of little use but for the pomp of ceremony. Széchenyi introduced the English racehorse and hunter, and to show their superiority, he instituted races, and kept a pack of hounds; in short, he succeeded in making English horses a fashion, which is now generally followed.

The races take place twice a year at Pesth about the end of May, and at Parendorf, near Presburg, in autumn; and are so well attended that it is evident that they suit the tastes of the people, and it is highly probable that they will one day form a part of the national amusements.

An improvement in the breed of horses was an object well worthy Széchenyi's attention, and nothing was more likely to promote it than the establishment of races in the capital; but some have thought that objects of a deeper interest than the

encouragement of thorough-breds might have been dreamed of in their institution.

The Diet ought, by law, to sit every three years, but when the government is strong, it sometimes dispenses with its services, as it did during and after the last war for twenty-five years, and then the nobles have no object of common interest to bring them together.

When minds clash not with minds they are apt to grow rusty, and lose some of their sharpness and polish; a thousand useful ideas and beneficial projects, a thousand high resolves and patriotic schemes, expire untried, unheard-of, from want of opportunity to communicate them to others.

This opportunity to meet and communicate the races afford; without a pretext for interference or interruption: many come, they know not why; the master-minds command, and they obey.

The system so long and so ably followed up, of Germanising Hungary, had succeeded to such a degree as to destroy, to a considerable extent, the feeling of nationality among the higher nobles; most of them were ignorant of the language, few of them took any interest in the affairs of Hungary, except in the preservation of their own privileges, and some even affected to despise their countrymen because of a little outward rudeness, of which the absenteeism pursued by the more polished and wealthy was the main cause. Fortunately the well-wishers of Hungary knew how influential a principle the spirit of nationality is, in the regeneration of a country, nor did they forget how strongly the language of one's childhood, with which man's earliest and dearest associations are connected, acts in exciting that spirit.

The restoration of the Hungarian language was, therefore, the first object. Széchenyi himself, from disuse, was no longer master of it; he made himself so, and became one of the most influential in its diffusion. He was the first in the Chamber of Magnates who spoke in Hungarian; till then Latin was always used in the debates, as it still is by the Palatine and the court party. Few thought of reading Hungarian—fewer, except some poets, of writing in it. Széchenyi published several political works in the language, and Hungarian authorship has become fashionable. Among men it is now the medium of conversation; at public dinners, toasts and speeches in German would not be listened to,

and at Pesth, whatever may be the case at Vienna, Hungarian gentlemen are now ashamed to be thought ignorant of the Hungarian language.

The establishment of a society for the development of the Hungarian language, was proposed by Széchenyi in the Diet, and was, as usual, met by innumerable objections; of which the want of funds was most cogent. "I willingly contribute one year's income," (6000*l.*) said Széchenyi—"I second it with 4000*l.*," said Count Karolyi György: the example was catching, and 30,000*l.* was soon subscribed.

I have some hesitation in speaking of the writings of Count Széchenyi, for I have never been able to master the difficulties of the language, and we all know that translations, even the best, convey but indifferently the spirit of the original. Many of his works, too, have not been translated, and of these, I can only give the title-page. It would be, however, too great an omission not to speak of what has produced so great an effect, and I shall, therefore, give a short analysis (from the German translation) of his "Hitel," or "Credit," the work which has been most read, and which has gained him the most fame.

The "Hitel" is an inquiry into the causes of the want of commercial credit in Hungary, with suggestions for their removal.

In the introduction, Count Széchenyi attacks one of the great drawbacks on Hungarian progress—the want of a common purpose and a common opinion. "All are anxious to build," he writes, "and every one at the same building, but, unfortunately, each wishes to lay his foundation-stone in a different spot, and begin his work in a different style. Many would like to commence in the middle, and some seem to think the best plan of building a house is to begin with the roof. Few set themselves to work at the foundations. 'Oh! if the Ludovica road in Croatia were but toll-free!' says one. 'Give me rather a suspension-bridge between Buda and Pesth,' answers another. 'First of all, let us lay out a promenade along the banks of the Danube, and plant it with trees, and while they are growing up, we shall have time to ——' 'No, no, I say a Magyar theatre, and the Magyar language, that will keep up our nationality!' 'Ah,' says another, 'if our rich magnates would only come and live at home, instead of spending all their money in foreign lands, and take a part in our county

meetings!'—'Tut, man!' grumbles a neighbour, 'that's nothing, if they would not bring those nasty foreign fashions into the country—those shoes and stockings, instead of stout Magyar boots, and those great hairy—what do you call them? *Colliers grecs*, in which they hide their honest Magyar faces!' 'The paper-money is our ruin, friend!' observes one; 'if we could only get hold of Kremnitz ducats, and keep Hungarian gold and silver within the boundaries of Hungary, then ——' 'Nay,' answers a second, 'but the salt-tax! if the salt-tax was but lower!'—and so on to the end of the chapter. Every man believes his own plan so much the best and wisest, that, without it, no step can be made in the march of Hungarian improvement."

Széchenyi next tries to persuade them that inquiry into their state will show them that their country is capable of much more than is at present supposed; enlisting even the laziest in his cause, by the lightness and familiarity of his illustrations. He then begins the more formal part of his work by proving that the Hungarian landholder is poorer than he ought to be, from the quantity and quality of his possessions, and that he does not possess those comforts which his circumstances ought to afford him.

He next shows that the Hungarian proprietor cannot, at the present moment, cultivate his land to the greatest advantage, because there is no mutual understanding among Hungarians, no commercial credit: while the common holdings of land, the monopolies and limitation of prices, the loss occasioned by compulsory labour, and the collection of rent in the form of tithe, all tend to impede improvements in agriculture.

From this Széchenyi goes to the subject of Commerce, and the causes assigned for its low state in Hungary are examined, the geographical position of the country, the want of capital, the inability to compete with other countries, and the amount and uncertainty of duties on exportation,—and he might have added, with more force, on importation,—are illustrated with a facility peculiar to the author,—the immediate causes of the want of commercial credit, he considers to be the excess of regulations, the deficiency of productions, the defective state of communication, the expense and uncertainty of existing means of transport, and the absence of that strict commercial probity, without which an extensive traffic can scarcely exist.

The means by which this credit is to be obtained, Széchenyi points out, and contends, especially, for the establishment of laws for the more certain and easy recovery of debts, and enforcement of contracts; and he combats most forcibly the arguments brought against this, on the score of the danger of extensive commercial speculations, the unconstitutional spirit of the laws delivering over the noble into the power of his creditor, the ruin and downfall of old families, which, it is thought, must be the consequence of them, and such reasons as an Englishman may hear every day, from a certain quarter of the House of Lords, in a debate on the usury laws. Here, as well, indeed, as throughout the whole work, the prejudices and follies, the ignorance and false pride of the Hungarians, Széchenyi has most severely lashed.

The example of England is frequently held up for imitation, and to the common objections cast against it, Széchenyi gives an answer, which shows how well he appreciates and understands the best part of our institutions:

"It is impossible," he observes, "to have visited England, and to have seen the vast progress which free institutions have enabled her to make, whether in material improvements, or in protecting the holiest rights of humanity, and not pity those miserable creatures who traduce so great a nation. England has faults as well as virtues, for earnestly as men may strive after perfection, and far as they may advance in the path, they are not doomed to reach the goal. But there are men who have no soul for what is good, and great, and beautiful, they ever seek and find nothing but the filthy and the bad—they are the unclean birds of society, and delight only in its carrion. Of such are the slanderers of Britain. They seek only the dark side, and they find it dark enough, no doubt; but from the light they turn away. There is much that is bad in England, from which God defend us! Above all, her 'intolerance' is always the first charge of her enemies, and that reproach we may make against her with a clear conscience, for, among ourselves, thank God! no trace of it exists. Then 'the misery of her manufacturers' is brought forward, and it means, perhaps, that they cannot every day eat beef and drink beer, to which they are accustomed, and of which, if deprived, they grumble at. With us more men live without meat than with it—many Wallacks never taste even a bit of good bread their lives long, and in the

neighbourhood of D—— there are hundreds who live throughout the summer on nothing better than water-melons. 'But,' perhaps, you exclaim, 'how happy they are, never to have known anything better'—enviable fellows, certainly!—'Then Ireland! * what do you say to Ireland?' Alas! it is too true, and we may well wonder that the English were compelled, from insubordination, to the necessity of depriving so large a portion of their countrymen of their common rights, without otherwise allowing a large portion a share in ruling it, while others enjoyed all the privileges, and all the wealth. Nothing could be worse than that!—'The National Debt.' There, indeed, we are more fortunate; of national debt—(not very oppressive to individuals after all)—we have none—but we have a precious quantity of personal debt, and by it we are crushed to the very earth. But are not such objections absurd? Is it not, fairly considered, seeing the mote in our neighbour's eye and passing over the beam in our own?"

If the "Hitel" were put into the hands of a mere political economist, he might find it, perhaps, too diffuse, superficial, and crowded with proofs of what he might imagine no one was ignorant; but to one acquainted with the country and the people for whom it was written, the book assumes a very different character. He is astonished with how much delicacy the best parts of the Hungarian character are seized and worked upon, how such prejudices as impede the progress of improvement are ridiculed and exposed; with what a richness and familiarity of illustration principles are taught, so that persons to whom such discussions are quite new, must still be struck with them; and with how much skill the author has managed in a treatise on political economy, to throw out hints to his countrymen on almost every subject, moral, economical, and political, which the actual circumstances of the country render important. The great lesson which Széchenyi constantly endeavours to impress upon his readers is, that the reforms necessary in Hungary, depend on the will of the Hungarians—that they have only to bestir themselves to effect a complete change in the moral and material aspect of the country.

The first reception of the "Hitel" was anything but encouraging; the satire was ill relished by those against whom it was directed;

* Before this work was finished, Ireland was reinstated in her natural rights.

its author was abused, written against, and, in one instance, the work itself was burnt by the common hangman, by order of a county meeting. Such was the state of feeling in 1830. In 1835, Count Széchenyi was receiving addresses of thanks from almost every part of the country; in Transylvania a magnificent gold pen was voted him, at a public meeting, as the most useful of Hungarian authors; and everywhere his name had become a watchword among the well-wishers of Hungary.

Among the later works of Count Széchenyi are the "Vilag" (Light), an answer to a pamphlet published by Count Desewffy, against the "Hitel," and a work on the practicability of a permanent bridge at Pesth.

Of the style, of course, I speak only from hearsay, when I pronounce it among the best in the Magyar language. To the accusation of coining and introducing new words, every one must be liable who speaks of ideas new to the people, and uses names foreign to the country. Some persons complained that they had turned over their Magyar dictionaries in vain for the word "Macadamise," which they very innocently conceived to be a creation of Széchenyi's.

In Hungary, a want of unity among the different ranks of the nobility, an absence of a common feeling, and of something like a general opinion, have been long among the most acknowledged causes of inaction. Every class discusses apart the subjects of immediate interest, forms its own opinions of public events, and its own plans for public reforms: the accordance which gives strength and force to action, is wanting. This deficiency was universally acknowledged; but without a free press, and with a Diet sitting but rarely, and then at a distance from the capital and centre of the country; without reports of the debates, without even a national literature, and in the midst of the bitterest jealousies of caste and class; what remedy could be proposed? Széchenyi had seen the clubs in London, and with that singular talent which he eminently possesses, of appropriating and adapting whatever he finds good in other countries, to the wants and deficiencies of Hungary, he easily perceived how useful their organisation might be made to effect a greater purpose than that of serving as mere pride-protectors for poor gentlemen, or of furnishing the selfish enjoyment of the greatest luxury at the

cheapest rate. A club, or to avoid a name associated on the Continent, with certain reminiscences of the French Revolution—a Casino, while entirely free from any political scheme, would afford to all the upper classes an opportunity of meeting, and of becoming better acquainted with each other's good qualities; it would harmonise and generalise opinions, and improve the manners and tone of feeling, besides affording opportunities for reading all the journals of Europe, an advantage which few private individuals could command.

At Pesth, accordingly, a Casino was established, on the most magnificent scale, as we shall see hereafter—and now, no less than one hundred exist in different parts of Hungary and Transylvania.

One of Széchenyi's favourite plans is, the embellishment and aggrandisement of Pesth. For this purpose he has laboured to have the Casino on so handsome a scale; to build a national Magyar Theatre; and, more than all, to raise a permanent bridge between Buda and Pesth. At present* there is only a bridge of boats between the two towns, which is taken up during six months in the year; and the whole communication during that period is carried on by means of ferry-boats, or over the ice. At certain times, particularly during the freezing and thawing, not to speak of storms and fogs, this produces much inconvenience, and is often attended with great danger. To remove so great a drawback to the prosperity of the two cities, Széchenyi has proposed to build a bridge across the river, either of stone or iron, as may appear best; and as the width is only a quarter of a mile, it would not appear so difficult an undertaking. Of course it was declared impossible. One said, the Danube was too wide, another found it too deep; a third declared, if the bridge was all finished the first winter's ice would carry it away. English as well as German engineers have thought otherwise; and it is a certain fact that Trajan's bridge, three hundred miles lower down, stood firm enough till Hadrian destroyed it.

These, however, were not the greatest impediments to be overcome. Count Széchenyi had a still greater object in view, than the improvement of Pesth, in building this bridge. He

* This work was published in 1839, since which the bridge has been opened to the public, and all danger of a stoppage of communication is at an end.

proposed to teach the Hungarian nobles the advantage of paying taxes. The bridge was to be built by money raised in shares, the interest on which was to be paid by tolls, to which every one, noble or ignoble, should contribute. What! a Hungarian noble pay taxes! A hornet's nest is a feeble comparison to the buzz these gentlemen raised about Széchenyi's ears. It was no matter: he inveighed against them at the Diet; he wrote at them in the journals; he ridiculed them in private; and in the end he conquered them. A bill passed both Chambers, by which the legal taxation of the nobles, in the form of a bridge-toll, was acknowledged. The Judex-Curiæ shed tears on the occasion, and declared "he would never pass that ill-fated bridge, from the erection of which he should date the downfall of Hungarian nobility."

Of the petty opposition which Count Széchenyi had to contend with, and the means by which he overcame it, I cannot speak here. I did not believe that any man possessed the indefatigable energy and perseverance necessary for the task. It requires a truly patriotic spirit to endure those miserable checks which arise from the selfishness and meanness of the very persons one is labouring to benefit. The corporation of Pesth did not think they were justified in giving up the tolls which the present bridge of boats brought them in; the proprietors of land would not sell for such a purpose; the owners of houses here, feared the new bridge would be there, because they knew it would be better there; the very toll-keepers had their friends and supporters, whose opposition at times made even a Széchenyi doubt of success.

One of Széchenyi's greatest achievements is the steam-navigation of the Danube. This is, however, his own in idea and in accomplishment. It is now about six years since he first undertook the voyage from Pesth to the Black Sea. A comfortable-decked boat, a good cook, and a pleasant companion, with the means and appurtenances for shooting, fishing, sketching, and rowing, were not bad preparations against the fatigues and dangers to which he expected to be exposed. The comparative ease and safety of the navigation, the magnificence of the scenery, the size and importance of the tributary streams which poured their waters into the Danube, and the richness of the country on its banks, were

secrets revealed to a mind which felt their full force, and happily knew how to employ them. Of course the timid set him down as mad for undertaking such a journey; but when he returned, and ventured to whisper the possibility of steam-navigation, even his best friends shook their heads. "Steam in Hungary! Yes, indeed, in another century," said those who never think the present the time for action. "Steam, indeed, in the shallows and rapids of the Danube! No: if we must have steam, why not take the plains? Nature has laid them out for railroads," said others, who oppose everything practicable by proposing something impracticable. Széchenyi let the first wait their time; to the second he recommended a speedy commencement of the railroad, that the country might derive advantage from one, if not both, of their schemes.

In pursuance of his own plan, Széchenyi went over again to England, studied carefully the principles of steam-navigation, brought over English engineers, and when at last certain of the practicability of the scheme, formed a company and purchased a steam-boat. It was in October, 1830, that the first steam-boat plied between Semlin and Pesth. The communication is now complete from Vienna, and will soon be so from Ratisbon to Smyrna. Thirteen vessels are employed, and a number more are building.

To detail the advantages of this undertaking in extending commerce, in developing the resources of the country, or in opening the road to civilisation, by the spread of intelligence, were only to narrate what every one knows steam-navigation has effected, and will effect, wherever it is introduced; but in Hungary it has done more, it has engaged one of the proudest and richest aristocracies in Europe in a profitable commercial speculation! We shall show elsewhere that it is to the exclusive privileges of this aristocracy that Hungary must impute in a great degree her want of commerce: how great a point has thus been gained will be easily understood.

At first, some of those whose hearts were better than their heads—and Hungary possesses a great number of that class—would not hear of profitable speculation. "If it would benefit their Fatherland no other consideration was required; it would be degrading so noble an object to mix it up with such tradesmanlike

calculations." Széchenyi thought otherwise, and he felt assured that a profitable patriotism was the one by far the most likely to endure.

Count Széchenyi's first object was, to make the undertaking answer as a commercial speculation. This is a favourite theme in his writings; the constant test by which he examines a new scheme. I mean if of a nature to which it can properly be applied; for no one knows better how to sacrifice all pecuniary interest when necessary. He never recommends a thing until he knows that interest will back him, and he can then chink his full purse in his opponents' faces, and laugh them out of their prejudices. Of all he has done for Hungary, I know of nothing more useful than these demonstrations of the co-existence and often necessary connection of public and private interest.

During the earlier part of the last Diet, a strong opposition was formed in the Upper Chamber, chiefly under the guidance of Széchenyi, which contained many of the most wealthy and talented of the rising generation. From their moderation, their union, their knowledge of business, this party, though small in numbers, was acquiring so great an influence, that all the power of the court was employed to break it up. The Transylvanian magnates* were called away by the opening of their own Diet. Those in government employ were hastily recalled to their bureaux. This man received a place or a pension, another desired decoration, and hung dishonour at his button-hole, and if a third was too high for such poor bribery, he was recommended to travel, and accepted a passport to convey him from the sphere of his duty. Széchenyi, though deserted, was more difficult to dispose of, but that "every man has his price," is always the belief of an immoral government, and they found the means of withdrawing the patriot from the fulfilment of perhaps the higher duty, by offering him a much more arduous one. Széchenyi was made sole commissioner for improving the navigation of the Lower Danube, and almost before the ink was well dried on his commission, a thousand men were at work, current dams were constructed, canals were cut, roads were laid out, rocks were blown up, and the very Iron Gates themselves were threatened with destruction.

* A Transylvanian magnate enjoys the rights of a Hungarian, if he holds property in Hungary, which many of them do.

Széchenyi kept to his maxim—to leave the uncertain and follow the sure and practicable—and I recommend those who so loudly condemn his choice, to go to Orsova and see the result.

Since this time, though very far from neglecting his political duties, Széchenyi has taken a less active part in politics than was expected of him. Perhaps disgusted and alarmed by the violence of the less prudent; perhaps fearing that an active personal opposition, while it effected nothing, might impede much material good; perhaps confiding in the good intentions of government, or it may be reposing merely till a more favourable opportunity arises of urging on the Diet measures of justice to the peasant, and of encouragement to commerce: it is certain, from whatever cause, that he has withdrawn himself in some degree from active opposition. Looking at the whole tenor of Count Széchenyi's public life, we feel convinced that he has not acted without reflection, and probably not without good reason, in withdrawing from the political arena for a time; but he must not forget how much Hungary, how much Europe, expects of him.

When a man has once embarked on the stream of public life, he has no longer a right to disappoint the just expectations of the world. When such a man fails, the honest confidence, the high resolves, the purest aspirations of millions, are sacrificed. One feels a sickening at the heart, a contempt of virtue, a hatred of one's kind, when the man we have worshipped as the idol of our hopes, deceives us in the expectations we had formed of him.

The Hungarians, however, need not entertain such fears; whatever be the difference of opinion as to the means, no one can doubt the rectitude of Széchenyi's object. It cannot be denied that the support of high moral principles, the unflinching advocacy of just rights, and the unyielding defence of the injured and oppressed, are yet more important to the well-being of mankind, than the mere improvement of their material existence. But few in the Hungarian Diet have fulfilled these duties better than Széchenyi, while the other objects at which he has so industriously laboured, the detractors of his fame have entirely neglected.

Those who read Széchenyi's works, and know the reception which they met with, who are acquainted with the excessive national susceptibility of the Hungarians, and who recollect how just, and therefore how bitter, was the satire he directed against

them, will not suspect him of seeking popularity, except so far as it is necessary to the furtherance of his objects.

That Széchenyi has not attempted what he could not do, and what others have failed in doing when they attempt, is at home and abroad no uncommon subject of complaint against him. To me, it appears one of his greatest merits to have known his own powers, to have calculated accurately how far his means would enable him to go; to have reflected deeply on the practicability, as well as utility, of a scheme, before he proposed it for adoption, would seem just those qualities which best entitle a man to the confidence of a nation, and which, when united to high talents, necessarily make him the leader of a party. But Széchenyi's objects and hopes are best described by himself in concluding the "Hitel."

"The contents of my work will prove to all that I hate all extreme measures, all excesses; that I am a friend of moderation and harmony. Gladly would I see parties unite, and much more willingly would I obtain, by a middle path, the *possible good*, than vainly strive after that imaginary bliss which we may probably never know but in a better world. I cannot, like many of my countrymen, please myself with contemplating what is past. I must look forward. It troubles me but little to know what we once were; but it is of vital interest to me to know what with time we might, and what we probably shall, become. The past is beyond our control, the future is still within our grasp. Away then with future reminiscences! It is time that we bestir ourselves, and open a more glorious future to our fatherland. Many contend that Hungary has been: I love to think she yet will be."

Since the publication of the above Memoir by Mr. Paget, in 1839, the Count Széchenyi's time was entirely taken up in devising, with his usual talent and extraordinary exertion, plans of all kinds for the benefit and aggrandisement of his country. Love of his country was with him the one great passion; and no sacrifice of his time, comfort, or peace was too great to attain his object.

Amongst the many and useful projects for improving the condition of Hungary, was that of connecting the River Danube

with the River Theiss by a canal 118 miles in length, by this means opening a new source of conveyance of the produce of the interior up to Tokay. A regular Survey and Estimate of this important work, with the preparation of a Geological Map of the district, was entrusted to Mr. Clark, as well as the forming of a tunnel under the Festung or Fortification at Buda, through a calcareous rock, thereby cutting off a steep and circuitous route to a most frequented road; and, with the view of ultimately forming a communication with the proposed railway from Raab to Pesth, the tunnel was designed wide enough to admit of two carriages abreast, with a footpath on each side. This, with other works and valuable suggestions, was delayed in consequence of the political state of the country, and ultimately abandoned, during the Revolution, to some future period; but never to be carried out by the great and disinterested patriot who first proposed it. He predicted all that has since happened. That his country would be ruined, and Kossuth become Dictator. He did all in his power to counteract the terrible drama that followed, but his wise counsels were unheeded; his mind gave way, and Hungary now deplores the loss of the advice and able assistance of Count Stephen Széchenyi.

REPORT OF THE BAU-DIRECTION

ON THE

STATE OF THE DANUBE IN 1832.

TOPOGRAPHICAL DESCRIPTION OF THE COURSE OF THE DANUBE, FROM THE LOWER POINT OF THE ISLAND OF ST. ANDREW, ABOVE OFEN AND PESTH, TO THE POWDER-MAGAZINE BELOW OFEN.

TRANSLATED FROM THE GERMAN.

After the junction of the two arms of the Danube, which form the island of St. Andrew, by Bekas Megyer to the right, and by Kaposztase Megyer to the left, the river is continually intersected by several considerable islands and sandbanks, viz., by the Island of Pesth, the Great Minor Island, "Grosse, Kleine Insel," Margaret's Island, and Dyer's Island. After having collected its strength below Margaret's Island, it firstly concentrates in the vicinity of the Ponton, and remaining in its full force to the extent of several hundred fathoms, soon disperses itself in its rapidly extended course, and divides into the two arms of the Danube, by which the well-known Island of Csepel is surrounded; the principal arm taking its course towards Promontori; the other arm being the Soroksara Danube.

The breadth of the river increases towards the upper parts, where it is divided by the islands, to the extent of from 400 to 500 fathoms and upwards, exclusive of the islands. After its juncture below the Island of St. Margaret, at G K in the Profile, it is from 480 to 490 fathoms broad, but afterwards decreases to 250 fathoms in breadth; next the Ponton it is from 220 to 230 fathoms, and it finally decreases to only 160 fathoms; this is at

C D in the Profile. Near the Blocksbaade, at L M in the Profile, it attains a breadth of 195 fathoms, whence it suddenly spreads to a breadth of 530 fathoms; it continues thus broad to the Island of Csepel, the two streams conjointly being 500 fathoms broad.

It cannot be passed over without observation, that the breadth of the river varies, one part compared with another, to the extent of 300 or 400 fathoms. The breadth of the river, or, more properly speaking, the natural boundary of the same within its limits, commencing from the Ponton, down to the Blocksbaade, being the narrowest portion, scarcely differs, as will be seen by the cross profiles, A B, E F, G H, C D, L M.

The depths of the river are no less surprisingly variable than its breadths, for in the upper range, where it is divided by the islands, its depth changes with the lowest ebb of the water, from five to ten feet only, usually, and seldom to twelve feet; in its lower range, from eight to, at most, fifteen feet, while in its concentrated course, it is from thirteen, fourteen, to at most, thirty-one feet deep.

On inspection of the chart of the locality, in the first instance, the impediment to the escape of the water seems to occur between the profiles E F, and L M, viz., in the vicinity of the mountain of St. Gerhard; but when recourse is had to the profile of lengths, and the cross profiles, and we consider at the same time, that the production of water depends on three dimensions, viz., breadth, depth, and velocity, it follows that the breadth is the most considerable dimension compared with the others, but that the other two, together, are greater: consequently, that the narrow parts of the river were calculated to accelerate much more water than the profiles, upwards and downwards, which are considerably broader but much shallower, if the shallow parts of the river occasioned by its excessive breadth, were not an impediment to the flowing.

For, according to the profile of lengths, there exists a dead water in the depths situated between the profiles, *a b* and *t u*, which is proved by the annexed calculation of the consumption of water. Thus, for instance, leaving the irregular profiles G H, L M, S T, U V, out of the question, and only comparing the cross profiles C D, E F, *c d*, with each other, which are quite sufficient for calculating the different states of the water as to its ebb and flood, the products of the water will be found to vary exceedingly, if in the calculation the water contained in the depths of the Danube

which contributes nothing to its flowing, be overlooked, when, on the contrary, a very near approximate product of all three degrees, viz., the lowest, middle, and highest, is obtained, if in the calculation, the dead water with the assistance of the profile of the lengths be taken into consideration. The rule, theoretically demonstrated, by which a channel can be constructed, most favourably to the flow of the water—viz., by having the smallest possible circumference, in order that its adhesion and friction, which retard the flow, may be diminished—is nearest answered by the space next the profile C D, as is evident from a comparison of the cross profiles.

From the form of the channel of the Danube at present briefly described, the very dangerous visitations to which both the capitals are exposed, accruing from the ice, at the time of high water, will be fully apparent; for where the river suffers a great diminution of its rapidity, where it deviates from its concentrated course near the Blocksberg, into its bed which is suddenly extended, and, with it, the power of impelling forward masses of ice also, just then, the course of the stream varies, on account of the sand-banks situated on the lower side, from the right shore verging towards the left, and, as appears from the annexed map of the breaking up of the ice in the year 1815, causes the ice to flow into heaps on those very sandbanks situated at the lower end of the city of Ofen; and this continues to place more obstacles to its course, but, especially, below the Camp Laager Hospital on the Pesth side, where the masses of ice are accumulated by the stream in the shallow Soroksarer part of the river; and in the upper point of the Island of Csepel a new obstacle forms itself, in consequence of which, its power, already diminished, is further reduced, as the curve of the river likewise becomes further extended in consequence of the accumulation or heaping up of the sand and ice; it is therefore evident that an obstruction of the masses of ice must follow, which impedes its breaking-up, and, very frequently, obstructs even the course of the river, which gives rise to a re-percussion, and thereby occasions the surface of the water to rise higher than usual; besides this, the Soroksarer arm of the Danube, which, according to computation, in its middle state, is capable of carrying off nearly a fourth part of the entire quantity, becomes completely blocked up by the heapings of the ice, occurring one after another

during the course of the winter, and consequently, the whole body of water is forced violently into the main arm, the profile of which is only formed for the product of water usually flowing through the same.

According to existing observation, the surface of the water rises, in such an extraordinary case, from 6 to 8 feet higher than the high water at any period of the summer, which, according to observations made at Ofen-Pegel, is hardly 16 feet above "zero;" whereas, the rise of the water, occasioned by the ice in 1830, attained to the height of 22 feet above zero, and that of 1775 reached the height of 24·2 above zero, being the highest within the memory of the inhabitants,* and which has been transmitted, with considerable care to posterity, by the construction of tables of marble immured in the walls of the thirtieth royal public edifice in Ofen, situated immediately next to the water, or "Wasserstadt," and also in that part of the city inhabited by the Raitzes, on the house of Dobrosklaai.

This extreme high water covered both shores, the latter being only from 19 to 21 feet above zero, whilst the water of 1775, as before stated, rose to the height of 24·2 above zero; even the wall, serving as a barrier at Pesth, against the inroads of the water, is only constructed 22½ feet above zero. It is, therefore, easy to form an idea of the devastation which both capitals must be exposed to in a similar case, but more particularly the city of Pesth, a great part of which, containing the most valuable goods and merchandize, is situated several feet below the level of the high water occasioned by the ice, and remains exposed to this extraordinary peril, devoid of all protection.

The Act of Inquiry instituted on the part of the Royal Hungarian Supreme Direction of Buildings (sub No. 810, 1832), in the royal free city of Ofen, confirms the misfortunes, universally

* As the word "zero" occurs several times in the course of the work, it will be proper here to give an explanation of its meaning. Several years ago, on the breaking up of the ice, it met with an obstruction in the shallow part of the river above Pesth, and stopped there. The ice, in the meantime, began to accumulate from above, until it formed a partial dam, which obstructed the course of the river, and caused it to fall several feet at Pesth. This low water (which lasted only a few hours) was marked as "zero;" not for any practical purpose, but merely to notify the lowest water ever known in the Danube. This, as will be seen on inspection of the Plans, &c., was used as the datum line in the construction of the bridge. This Report was published in 1832, since which time a flood considerably higher than that of 1775 has occurred, viz., in 1838, as will be seen on reference to the plates.

known and handed down by tradition, caused by the high water occasioned by the ice in the year 1775, according to which a considerable number of houses are stated to have been thrown down, and a great many persons perished in the inundation.

According to the said Act of Inquiry, in the year 1775, the blocks of ice were an ell and a half thick, and piled up in many places above 12 feet in height.

When the water is not so high, the Waitzner-street dam forms an effectual source of defence to the city of Pesth, as that dam cuts exactly through the low grounds by which the high water, beginning at the upper end of the city, would effect its escape through the Lakefield gardens into the town suburbs, Theréze, Joseph, and Francis, and would disgorge itself into the Danube by means of the Wood-dam, by which the lower part of these low grounds is protected from the waters of the Danube.

In the aforesaid low grounds, traversing the city, which, from traces still discernible, appears at one time to have formed an arm of the Danube, a principal divisional channel is cut, and from the dam a canal under ground has been constructed, by means of which the water from the ground, from rain or snow, is conveyed out of the city into the river, at the same time the high water is prevented from making its way into the city.

It is to be attributed to the Waitzner-street dam—which, by dint of continual watching, and being kept heaped up, was enabled to prevent the high water of 1830, occasioned by the ice, from making its way to the low grounds, that this high water was productive of very trifling damage compared with the devastation which occurred during the year 1775, and that merely by waters from the ground in the capital of Pesth; likewise on the Ofen (or Buda) side, the high water of 1830 was, comparatively, much less destructive than that of 1775, for the reason that, since that catastrophe, the foundations of the houses have been considerably raised.

It results from what has been already stated, that the high water in summer is productive of no damage to either of the capitals, whereas the extraordinary high water which is produced by the stoppage of the ice, involves them, on the contrary, in the greatest peril; and this stoppage is to be ascribed to the present form of the bed of the river—that is to say, from the immoderate breadth, and obstruction of the channel by sand.

From this may be drawn the inference, that if the breadth of the stream of the Danube, from the Blocksburg to the powder-magazine guard-house, below which the river seems to have a regular bed to a considerable extent (as to which, however, the practical survey still remains to be taken) were lessened, the main cause of the danger of the stoppage of the ice would be removed, and would be productive of the most beneficial results to both the royal capitals: also by the construction of a permanent bridge; and for this reason, it might be well worthy the attention of both the royal free capitals, and also of the Bridge Building Association.

The descent found by the level, in the state of the water, three feet five inches above the lowest ebb, varies from the Bekas Megyer frontier to the Ponton, from three to six lines per 100 Vienna fathoms.

From the Ponton downwards to the Blocksburg, the descent is only two-and-a-half to three lines per 100 fathoms; whence, downwards to the extreme point of the operation, viz., to the Powder Magazine, the descent is eight lines per 100 fathoms. The total descent from the lower point of St. Andrew's Island, above Ofen and Pesth, to the Powder Magazine below Ofen, a distance of 8800 feet, amounts, in the state of the water quoted, to 3′ 6″ 9‴, which gives an average of 5·8 lines per one hundred fathoms.

This inconsiderable fall from the Ponton downwards indicates the existence of an impediment below, which opposes the flowing of the water, and, consequently, the lowering of the surface.

Although the extent below the Ponton has the least descent, yet the greatest velocity was found in the same, as is proved by the cross profiles, and the annexed table of the consumption of water, which is only to be ascribed to the contracted force of the stream, on account of the regularity of the channel, for with the descent of the river, under similar circumstances, the velocity increases, because that is the operative cause, unless it be retarded by the increased friction and adhesion consequent on the larger circumference of the bed.

The river here contains small "schotter" and river-sand, here and there intermixed with mud and silt.

The bottom of the river is firm throughout; near the St. Gerhard's Mountain from the cross profile C D to below L M,

the rocks extend from the mountains to the middle of the river, but, very fortunately, they are situated so deep as neither to impede the flow of the stream nor the navigation of the river.

From the upper end of the Market of Old Ofen to the Ponton, the shores consist of street-earth; from two to fourteen feet, there is deep, slimy mud or loose earth; then follows a layer of clay, and this again is succeeded by "schotter."

In the same extent, but more distant from the shore, the loose earth attains a depth of thirteen feet; after which follows a stratum of blue loam or potter's clay, and under this, again, yellow clay.

In the vicinity of the Ponton, the ground above consists of street-earth and rubbish to a depth of fifteen feet; then loam succeeds, and, finally, the rocks which extend from the Mountain of St. Gerhard into the river.

From the extremity of the city of Ofen to the Powder Magazine, there is loose garden earth to a depth of twelve feet; then follows a stratum of clay, three feet thick, and underneath another of "schotter."

Along the whole range of the city of Pesth, after a sandy street-earth to a depth of two feet, follows a loose earth mixed with slime and sand to a depth of fourteen feet, afterwards a stratum of "schotter" eight feet thick, under which there is river sand, two feet thick, and this is followed by clay-earth.

The elevations of the shores and grounds, made apparent by the profile of the lengths, expressed as they are by marks "bottom" in the map of the locality: those only—above the lowest water—of the mountain of St. Gerhard and the fortress of Ofen, are given:—

	Feet.	Inches.
The Mountain of St. Gerhard, near the Observatory, is	432	0
The Mountain of the Fortress, in the Royal Palace Court, is	186	3
The Mountain of the Fortress, St. George's Place .	211	4
The Mountain of the Fortress, Trinity Place . .	230	2
The Mountain of the Fortress near the Garrison Church	219	3

All above the lowest water-mark, or "zero."

AS RELATES TO THE NAVIGATION.

The course upwards, or the passage downwards, is free above the island of St. Margaret in the main arm, afterwards on the side of the island of St. Margaret in the Pesth arm, further below the mountain of St. Gerhard in the whole breadth of the Danube, and then ranging with the course of the river, doubling the sand-banks, into the main arm of the Danube towards the Promontori.

The counter-passage goes on without impediment the whole extent from the Powder Magazine to the point of the island of St. Andrew on the right shore, when the water is high; but when it is low, the course of the navigation must be round the sand-banks, Kopaski and Hasenlauf, situated below the St. Gerhard mountain, with great force and loss of time. The same in Old Ofen, in order to avoid the shallow arm of the Danube, they must tack and stand for the great island, and back towards the right shore. The Soroksarer arm is only navigable by the inhabitants on its banks in small craft, and even the navigation thus carried on is interrupted when the water is low.

According to 5 B of the Act of Inquiry at Ofen, the largest ship-mill,* from top to bottom, is 3 fathoms high, and draws 2 feet 6 in. of water.

	Feet.	Inches.
The height of the largest mill is	15	6
The greatest breadth is 8 fathoms	48	0
The greatest length, 9½ fathoms	57	0
According to 7 B, the height of the largest hard-ship is .	21	0
The height of the greatest soft-ship is	27	0
According to 6 B, the height of the greatest soft-ship is .	18	0

According to 7 B, the largest empty oak-built vessel immerges 2 feet deep, when laden 6½, at most 7 feet.

The breadth of one of the largest Danube vessels is 3° 4′, at most 4° 1′ = 25 feet.

According to 7 B the largest Danube vessel, without her helm or rudder, is 27° to 28°; according to 6 B up to 32° in length.

* These ship-mills are in use on the Danube for grinding corn, and are worked by the stream.

The measurement of the rudder outwards, from the extremity of the vessel, is 2½ fathoms, including the tiller as much as 7½ fathoms.

However, the height of the vessels in 7 B seems to be over-estimated, as, according to the examination actually effected, the height of the vessel of largest dimensions now riding here at anchor is only 14 feet 6 in., which agrees more with 6 B, that the largest soft-vessel, from bottom to top, is at most only 18 feet high.

For the ROYAL HUNGARIAN SUPREME BUILDING-DIRECTION,
OFEN, the *5th July*, 1832.

Six years after the date of the above Report, viz., in 1838, a flood again occurred, which, in the height to which the water rose, and the damage caused by it, was without precedent in the traditions of Pesth. The ice in the river, near the piers of the proposed bridge, was six feet thick on the Ofen side, and ten feet on the Pesth side, in the beginning of February—a great part of this thickness, however, consisted of congealed snow. In this state it continued until the morning of the 9th of March, when a movement of the ice took place across the whole breadth of the river, and for about 350 yards in length,—the whole moving in one solid mass, where it remained until the afternoon of the 13th, when a similar movement took place for about 400 yards in length. It remained here for about three hours, when a general break-up commenced. The ice, however, stuck fast in the narrow section of the river opposite the Observatory, which caused so rapid a rise of the water, that by eleven o'clock in the night a great part of the town was inundated. About two o'clock in the afternoon of the 14th, the ice moved from the narrow part of the Channel, opposite the Observatory, but again stuck in the shoals, where the river divides at the head of the Island of Csepel, causing the water to rise to the extraordinary height of 29 feet 5 inches above zero, on the morning of the 16th of March, at which level it stood for a few hours, when it rapidly commenced lowering; and, forty-eight hours

afterwards, was down to 20 feet 10 inches above zero; but, although the highest water lasted but for a few hours, the damage sustained was enormous. A great part of Buda, and two-thirds of Pesth, were destroyed, and a great many lives lost.

The Count Széchenyi was indefatigable in his efforts to alleviate the distress caused by this terrible catastrophe. The Baron Sina contributed 4000*l.*, and likewise interested himself in the most praiseworthy manner to afford help to the sufferers.

REPORT OF W. TIERNEY CLARK ON THE PROPOSED BRIDGE AT PESTH, 1837.

VIENNA, *26th September*, 1837.

SIR,

I think it necessary, having been chosen by you to conduct the building of a permanent communication between the towns of Buda and Pesth, to call your attention to those points of difficulty which have come under my consideration.

The intercourse between Buda and Pesth is, at present, very great, and, no doubt, will greatly increase; it is, therefore, necessary for the anticipated traffic, that the communication should be of a safe and solid construction, and I am sure that you would not, in your high position, connect your name with any enterprise promising only a temporary utility and splendour; nor would I, after the various works which I have completed, undertake the conducting of a work but upon the most safe and stable construction, and calculated to last for many centuries.

By the preparatory works of the Directory for Public Buildings, and which was communicated to me by Counts Andrasy and Széchenyi, in the year 1832, and since which I have devoted much of my time to the consideration of the subject, and from the information which I have obtained during my visit here in 1834, and my late investigation at your request, I am of opinion that the description of bridge best adapted for either of the situations represented by the various plans and sections, for forming a permanent communication between Pesth and Buda, is a Chain Suspension Bridge, as the limited number of piers required will oppose much less obstruction to the flow of the water and ice than either a stone or cast-iron bridge. And this opinion I communicated in a report of the 10th of November, 1832, to Counts Andrasy and Széchenyi, and since my late examination of the locale, I am more confirmed in that opinion than before.

A bridge with stone arches could be built to cross the Danube at either of the situations represented by the plans and sections; but it would be attended with great risk, owing to the consequent number of piers which would be exposed to the flow of the water

and ice; so that, if the piers themselves did not endanger its completion, there can be no doubt whatever that their number and size would greatly enhance the danger of inundation. In addition to the above difficulty, it is not possible to obtain a good approach on the Buda side, without the destruction of considerable private property.

A cast-iron bridge, supported on stone piers, would be preferable to a stone bridge, inasmuch as a less number of piers would be necessary, consequently there would be less obstruction to the flow of water and ice; but it would be subject to the same inconvenience on the Buda side for an approach. But by far the greatest difficulty to encounter in the building of a cast-iron bridge would be that of procuring the necessary castings and workmanship, both of which must be of the very best description, and the parts of such large dimensions, that the transport would be next to impracticable if cast in England, which I am inclined to think would be requisite; as, from the best information I have been able to obtain, there is not sufficient experience and means on the Continent to undertake such a work.

A wooden bridge could be built on stone piers, as in America; but it would be, from the number of piers requisite for its construction, extremely objectionable; and as the entire of its superstructure would be composed of timber, its durability could not be permanent, and its annual reparation considerable, which would by no means answer the purpose you and the legislature of Hungary have in view; and the more I have investigated this subject, the more I am convinced that a chain suspension bridge, under all the existing circumstances, is the best adapted to form a communication between Buda and Pesth; and from past experience I am convinced that such a bridge could be built to answer the purpose with perfect security; but it is necessary to call your attention that no expense must be spared to render it perfect in all its parts. It is not necessary for me to trouble you with the number of suspension bridges that have failed in France; but it is incumbent on me to explain, as briefly as possible, that they have failed principally from want of proper knowledge and experience, so necessary to ensure stability and security; and, in general, the money allowed for such works has not been sufficient to render them permanent structures. On the other hand, the

suspension bridges built in England, under the direction of the late Mr. Telford and myself, have stood unimpaired up to the present time, and as firm as on the day they were first opened, and no time can be anticipated for their decay. But suspension bridges can be constructed of greater strength than those now in existence.

Next to the practicability, the amount of capital is to be taken into consideration, requisite for the building such a bridge; but on this subject it is difficult to give you any certain information, as so much depends upon circumstances over which there is no control; for a favourable winter during the time of building may reduce the cost, and an unfavourable one greatly enhance it.

The iron and stone work may be calculated nearly; but as the bed of the river, and the banks on each side, are chiefly composed of sand and clay, and the depth of the water varies from its ordinary state to a rise above it of twenty-five feet, it is therefore quite impossible to obtain a good and certain foundation without the aid of coffer-dams for the piers and the abutments. If there was any certainty that the season would prove to be dry, the coffer-dams could be made for one-half the sum necessary to contend against a season abundant in water; but, as this cannot be foreseen, it is necessary to contend against extreme contingencies; and the time from spring to autumn, even in a mild season, will be scarcely sufficient for finishing one coffer-dam in the river; but if the following winter be mild, the coffer-dam may remain safe, and the pier and masonry greatly advanced; but if, on the contrary, the winter should be severe, and produce large masses of ice in the river, the coffer-dam may receive injury, the reparation of which may be costly, and money and time lost; and with structures of this kind, that yield no income until quite finished, it is necessary for you to take this most particularly into your calculations. But if several severe winters follow each other, as I understand is often the case, there are no data for me to found a calculation upon with any degree of certainty. That you may have some idea of the cost, to found your calculations upon, it is here necessary to observe that the estimates furnished to Counts Andrasy and Széchenyi in 1832, were for bridges of the strength now in use in England; but since I have seen the situation, I am of opinion that the bridge should be made stronger than any now

in use: and I think, under all the circumstances, that a good and substantial bridge could be built, at the point shown on the accompanying plan, at a cost not exceeding 300,000*l.*

In respect to the iron-work, I am most decidedly of opinion that it cannot be manufactured on the Continent with that degree of soundness and accuracy so absolutely essential to ensure security, added to which, it will require constant personal attention of myself or agents, during the progress of manufacture and proof.

I have examined several stone quarries, and the result is that the Wolfsthal and the stone of Csobánk will answer the purpose required.

The situation which I recommend for the site of the proposed bridge will be seen from the accompanying plan, and although I have examined the other situations marked on the plan, and have no doubt that a bridge could be erected at either of the sites; yet that which I have fixed upon is the best, in my opinion, because on the Buda side it will be seen, on referring to the plan, that the fortress-hill is so far from the river, and the ground, both longitudinally and transversely, is so favourable for an approach as to require very little alteration of the present carriage-way to make the ascent of the bridge very easy. On the Pesth side also, the ground is very favourable, and an ascent equal to that on the Buda side can be obtained without interfering with any buildings, and the bridge would be better situated in this spot for the general convenience of the public.

A foot-bridge could be erected of one span as marked on the plan, and the cost of it would be about 120,000*l.*

During my stay at Pesth, great anxiety was expressed by many persons that the piers in the river could not be made to stand against the ice, and that their size would cause inundations; and that it would be absolutely necessary that myself, or some competent person appointed by me, should pass a winter on the spot, in order to observe the breaking up of the ice; but the observations which I have had made at St. Petersburg and Sweden relieve me from the apprehensions I have heard so strongly expressed; and I am confident that the produce of ice in the Danube will never affect the piers; and as regards the apprehensions expressed that the piers will cause inundations, these are also futile; for as the same sectional area will be preserved at the proposed bridge as

there is at present at the narrowest section of the river, there can be no danger whatever. I also heard during my stay at Pesth, that it was intended to regulate the banks of the river, and there can be no doubt that they require it very much, and the keeping and upholding of the banks should be under proper directions, and the police should be employed to prevent dirt and other rubbish being thrown into the river, which, being washed down when a rise of water occurs, lodges on the Island of Csepel, and thus increases its size, which has been going on for centuries, and, no doubt, adds to the risk of inundations; and some coercive measure should be enforced to prevent, as much as possible, farther accumulation; but provided this regulation takes place, it will in no wise interfere with the works of the proposed bridge, as they may proceed together or separately.

On my return to England, I purpose sending to you, on or before the 10th day of November next, a plan and section of the proposed bridge, showing the situation of the piers, with the inclination or rise of the road, or approach to the bridge, on each side of the river. And I have no doubt whatever that in case the works be done according to my design (of which I shall take care), that it will answer the intended purpose, and be a long and lasting edifice.

(Signed) W. TIERNEY CLARK.

To the Baron Sina.

CHAPTER I.

SOME ACCOUNT OF THE PROGRESS OF THE WORKS.

1839—1845.

1839. In the month of May, 1839, the royal assent was given to the project of connecting the cities of Buda and Pesth by a suspension bridge.

The Baron Sina having entrusted the entire execution of the bridge and works to Mr. Tierney Clark, with power to choose his own English staff of assistants, the following were chosen to conduct the several departments specified below, viz. :—

W. TIERNEY CLARK, F.R.S., Engineer-in-Chief.
ADAM CLARKE, Resident Engineer.
JAMES TEASDALE, General Clerk of the Works, Superintendant of Pile-driving, and (in consequence of the death of W. WARDROBE) Superintendant of Masons' Work also.
BLAND W. CROKER, Superintendant of the Chain-bars, made by Messrs. HOWARD & RAVENHILL, of the King and Queen Iron-Works, Rotherhithe, London.

The following is a Journal of the proceedings :—

In the September following, Mr. Tierney Clark had two trial piles driven through the bed of the river into the clay beneath ; the piles were of fir, but differing as to hardness, and the following were found to be the results of the experiment :—

The first pile was driven 20 feet 6 in., and the second 22 feet below zero, and therefore 4 feet into the clay substratum.

On leaving off driving, it took 30 blows with the monkey, with a fall of 25 feet to drive the first and hardest timber pile $\frac{3}{16}$ths of an inch.

The same number of blows with the same fall drove the second and softest timber pile barely $\frac{1}{8}$th of an inch.

From 12 to 16 blows were sufficient to upset the top of the first

pile, so as to entirely destroy the effect of the blows, until the damaged part was cut off, and the pile relooped.

From five to six blows were sufficient to produce the same effect on the second pile.

The outside of both piles was splintered and shaken a little; the first and hardest rather the most. The results of the driving, however, were considered satisfactory.

During the following autumn, the space required for the fixture-pier on the Pesth side—being that with which it was proposed to commence—was enclosed, and the excavation of the ground commenced. About 8924 cubic yards were removed, part of which was used to level the building-yard, which was very uneven, and to raise the floors of the sheds, magazines, and workshops, about a foot above the level of the rest of the yard, and part to fill up and level the space below the site of the coffer-dam where the high part of the shore receded very suddenly, by which a useful level space was gained, and likewise formed a part of the approach to the wharf. The position of the coffer-dam and wharf for this, called No. 1 pier, will be seen on reference to the map.

Before December, the whole of the space necessary for the coffer-dam, work-yard, &c., was enclosed by a strong fence 8 feet high, with proper entrance-gates, a magazine for stores and materials, and a small brick-house containing an office, rooms for watchmen, &c.

Shops for smiths, carpenters, and others, and a wharf were put in hand in the autumn, and finished during the winter and following spring.

1840. As the quantity of timber required in the construction of the coffer-dams would be enormous, the first endeavour was to procure the transmission of a sufficient quantity at stated periods, and this, from the great distance of the forests and bad state of the roads in almost all seasons, was attended with no little difficulty.

The fir-timber had to be brought from Bavaria and the forests of Upper Austria, the oak from Sclavonia, and the larch from the Styrian mountains. The Sclavonian oak is so remarkable for its size and magnificent appearance, that a short description of it will perhaps be acceptable.

Those trees near Podgeize, in the vicinity of the Save, which is the boundary between Turkey and Sclavonia, are more especially

celebrated for their superior height, grandeur, and quality as timber, although the forests, interspersed over Sclavonia, produce trees nearly as fine. Many of them rise to a height of 50, 60, and even 70 feet, without a single branch or knot, perfectly straight like some tall column, for 80 feet and upwards, when the top branches begin to spread out. The most curious circumstance about these trees is their small diameter at the root compared with their height, and diameter at top; some at 70 feet from the ground being 23 to 26 inches, while at the base their diameter is not more than from 39 to 48 inches.

Der Frauben Eiche (grape oak) is so called from the manner in which the acorns are clustered together, at the end of a very short and scarcely perceptible stem on the young branches. The acorns are small, short, and egg-shaped, and provided with a fine thorn at the top. When ripe, they are of a dark brown colour. The fruit-cups resemble leather, with a rough scaly skin, and are clustered together from two to four and even from six to twelve, on one stem.

The bark on the young trees is smooth, and of an olive-green colour; when grown, rough and of a brownish-grey; when aged, ash-grey, and covered with deep and regular furrows, the interior of a rusty red.

The Stiel oak, so called from the long stem or stalk on which the acorn hangs. The acorns are large, roller-shaped and rounded, with their points blunt, and when ripe of a leather-brown colour. The fruit-cup is woody, and provided with a fine hair, particularly round the edges.

The wood is heavy, hard, and tough, and the fibre fine. When young the wood is white, but when full-grown it becomes brown. Towards the heart this wood is much tougher, and less liable to splinter than the "grape oak."

The weight of the Sclavonian oak is, generally, about 55 to 60 pounds per foot cube, and some was found which *sunk* in the water. When perfectly dry, it loses about one-third of its weight, being then about 36 to 40 pounds per foot cube.

This timber was delivered at the works at Pesth, in lengths of from 40 to 80 feet, and 15 inches square, at the rate of from 50 kreutzers to 1 florin per foot run.

The manner in which large timber is usually got out of the forests is, in the depth of winter on sledges, when the ground is

covered with snow and frozen, or in the height of summer when the marsh lands are dry. The whole, or nearly the whole, of the forests are inundated in the spring, when the snow melts on the mountains.

It being found impossible to square the timber with any accuracy in the forests, this was obliged to be deferred until its arrival at Pesth. The whole of the Sclavonian peasantry use the axe extremely well, and this proved of great advantage, as 300 or 400 men could at any time be procured at a few days' notice. The distance from the forests to Pesth is about 160 miles.

The excavation for the retaining pier was finished about the middle of March, 1840. The ground was taken out to a depth of 3 feet 6 inches above zero, which was as low as the state of the Danube would allow, with the use of pumps. (Plates III. and V.)

In the month of April, Mr. Adam Clarke, the resident engineer, by direction of Mr. Tierney Clark, visited the iron-foundries of Styria, in order to ascertain what amount of iron-work could be obtained in the country, without having recourse to the great delay and expense attending its manufacture in England. He found their workmanship tolerably good, much better, in fact, than was expected; and, in future, it was decided, all the shoes, rings, bolts, &c., should be made there. A quantity of pile-shoes, besides other iron-work, had been previously shipped, viâ Trieste from England.

The following were the prices of iron-work, delivered at Pesth, from the foundries of Styria:—

Common-pointed shoes, 22 florins; broad bevil shoes, 24 florins.
Driving-hoops, bolts, plates, &c., 18 florins per Vienna cwt.*
Bar-iron, according to quality, from 9 to 13 florins per centner.
Cast-iron, from 9 florins 20 kreutzers (which was the price of the roadway beams) up to 15 florins, the price of the truss-columns, and of the ornamental sockets for the trussing of the platforms.

Mr. Adam Clarke from Styria proceeded to Upper Austria, from whence the fir timber had been ordered. He found it exceedingly good, close-grained, well-grown, and free from knots, being nearly the same, both in appearance and quality, as the *first* of the

* The Vienna cwt. is about five-sixths of the English cwt.

trial-piles, which were driven by order of Mr. Tierney Clark in the previous year.

A great quantity of timber was cut and squared ready for the first dam, and only waiting to be conveyed to the Danube, but this could not be accomplished until the melting of the snow, as the whole of it had to be floated to the river by small streams which were at that time nearly dry, and it was not until the 24th of May that the first ship-load arrived at the works.

The whole of the piles and other timber required for No. 1 dam, with the exception of the two inner rows of oak piles, were contracted for to be delivered at Pesth for the sum of 24,000 florins (2400*l.* sterling).

Mr. A. Clarke likewise examined a large extent of forest country, between Linz and Salsburg, for the purpose of ascertaining whether timber of sufficient quantities, and the requisite dimensions, could be obtained, in case it were decided, from the experience of the ensuing summer, to construct the remaining three coffer-dams entirely of fir. No difficulty was anticipated, provided proper time was allowed, in providing all the timber necessary, with the exception of the 70-feet piles, which could be obtained only in Sclavonia.

Arrangements having been made for the requisite supply of timber, and the manufacture of the iron-work necessary, the next difficulty that arose was to provide for the great quantity of stone that would be required in the next and following years.

Several quarries in Hungary and Austria were examined in 1838, by Mr. Tierney Clark, who reported on their relative merit to the Baron S. G. Sina and the Count S. Széchenyi; among those he considered likely to afford stone of good quality, and of sufficient dimensions, may be mentioned those of Wolfsthal and Mauthausen for granite, Soskut and Waitzen for soft and hard stone. The stone in all these quarries was good, but the tools and apparatus of the proprietors so imperfect, that it was found necessary to send for English quarrymen and workmen to superintend the working of them, and to teach the natives to make use of proper tools, without which it would have been hopeless to attempt to raise the large blocks required, some of the blocks being 10 feet long, and 10 to 12 tons weight. The granite was obtained from Mauthausen, but the great distance from the works formed a serious drawback,

being no less than 270 miles—it was brought down in barges to Pesth; the barges as they arrived were purchased by the Bridge Direction; some were broken up, and the remainder kept for the purpose of supporting the platform during the process of raising the chains.

During the spring, the piles for No. 1 dam were squared and trimmed perfectly true, in readiness for the contractor for the dam, Mr. George Burge of Herne Bay, whose agent arrived on the 18th of July, together with his clerk of the works, and seventeen workmen: this number, however, proved insufficient, for the natives were found to be so inefficient at pile-driving, that it was requisite to send immediately to England for more men—two English workmen being found absolutely necessary to each pile-engine.

About the 20th of July the staging for the first dam was commenced.

On the 28th of July, 1840, the first pile was pitched for No. 1 dam.

The piles at the head of the dam drove tolerably well, but those forming the returns much stiffer, from the greater depth of material. Some of the piles were broken, and obliged to be redrawn, in consequence of which it was determined to try the experiment of driving the piles in bays, and to dredge out the gravel in front of them, at the same time driving. This plan was found to succeed perfectly.

Mr. Tierney Clark arrived at Pesth on the 4th of September, 1840, and from the results of experiments made during his stay, came to the conclusion that the best Austrian fir was quite equal in quality to oak. It was therefore decided that fir of the best description should in future be used instead of oak.

Mr. Clark found the pile-shoes and other iron-work furnished by the Styrian manufacturer, Mr. Sesler, satisfactory: but it was necessary to order the iron rings for the piles to be made of the very best Styrian iron, as the Hungarian iron is by no means to be depended on, owing to its defective preparation.

A crane was by this time fixed for unloading the timber, which began to arrive in considerable quantities; and the wharf was extended up to the site of the coffer-dam, whereby much of the expense and time occupied in removal was saved.

Considerable difficulty was experienced in driving the piles

through the hard bed of gravel which overlies the clay, after they had been got down to that stratum with comparative ease by the use of the plan mentioned; this gravel being of such compactness as to shake the piles very considerably, and screw-glands were found necessary to prevent them splitting. Many of the piles had to be withdrawn, and it was found on examination that the shoes had been displaced. To remedy this, the shoes were riveted on, in addition to the nails, and for the future the piles were ordered longer than absolutely required, to allow for re-heading.

A twenty-five horse engine with pumps was at this time making in England, but it was found that at the back of No. 1 dam, where the engine was to be fixed, there was a running quicksand; it became necessary, in consequence, to extend the dam all round, in order to keep the shifting sand in its proper position.

It having been arranged that Nos. 2 and 4 dams should be commenced the following spring, the requisite iron and timber was ordered immediately, as well as eighty pile engines.

An ice-breaker or dolphin was also constructed during the latter part of the autumn, a little above the site for No. 2 dam, or that for the tower nearest the Pesth shore; this dolphin, which served as a protection against the ice, rafts, &c., was constructed at this time, so that a means might be afforded of judging of the actual force of the ice during the winter ensuing; and the event proved that its construction was most fortunate, as the winter of 1840-41 was unusually severe.

After the excavation of the gravel as detailed above, from $1\frac{1}{2}$ to 2 days sufficed to drive the bay-piles: the gravel was dredged out to within 5 or 6 feet of the clay; and after the piles had been driven home, the operation of dredging out the gravel was continued all round the dam, as well as at the returns, and the result proved most satisfactory.

Some experiments were made with the clay from Alt-Ofen, as to its capability for making good puddle, for filling in between the rows of piles, shown on the sections of the dams (Plates XIV. and XV., &c.). A specimen sunk in the Danube, without any admixture of gravel, soon got as soft as mud; while some that had been mixed with about a third clean gravel, had set quite solid.

The piles for the dolphin above the site of No. 2 coffer-dam, drove very well; the time of driving generally, including pitching,

was $1\frac{1}{4}$ day. Several of them were driven 7 feet into the clay and took $1\frac{1}{2}$ day to get down, going at last $\frac{1}{4}$ of an inch at a blow, with a 15-feet fall; the oak piles could not be got down deeper than this, as they began to split, and no fir piles long enough could just then be obtained; the piles drove much better and penetrated deeper than those for No. 1 dam, in consequence of the gravel being of a very loose and yielding nature, whilst that at No. 1 dam was almost as compact as rock, and gave as much trouble as the clay itself.

In the month of December the dolphin was finished, and no sooner was it completed than an extremely hard frost set in, and early in that month the Danube was covered with masses of floating ice, some of which struck it with tremendous force; being, however, well bolted together and secured in the strongest manner, no damage was sustained.

No. 1 coffer-dam was likewise not at all injured by the violence of the shocks, for, after the first day or two, the land-ice, by extending some 10 or 15 feet further than the front of the dam, formed a complete protection against the floating ice in the river.

The floating ice continued to increase up to the 15th of December, when it became so dense as to cut off all communication with the dolphin until the 18th, when it became stationary (in consequence of the resistance of the land-ice) to about 10 feet beyond the dolphin. The ice in the middle of the river continued to move until the 21st, although almost imperceptibly, on which day a regular communication between the towns was formed over the ice.

1841. The ice continued firm until the 17th of January, when, at about 3 o'clock P.M., it began to move in one unbroken sheet from the dolphin, where it had parted, to the Buda shore; a few minutes afterwards it began to move from side to side with tremendous violence. A stage, on which were three pile-engines for driving the piles on the upper part of the dam, was carried away instantaneously by the enormous force of the ice, which came crashing on till it touched the outer row of piles of the dam, when, after a squeeze which threatened to smash every timber, it broke up into small pieces, which kept rising up as forced on by the pressure behind, and formed an embankment against the side of the dam. The whole lasted about 10 minutes

and the first squeeze was the worst the dam had to contend with, but owing to the solidity of its construction, not the slightest damage—if we except that to the small stage above mentioned —was sustained.

A small space was always kept clear of ice, both round the dam and dolphin; as, in the event of the ice rising up perpendicularly, as sometimes happens, the piles might be forced out, and as much damage done in that manner as by lateral pressure.

The effect of the first pressure of ice on the dolphin was such as to create an apprehension that it would be entirely carried away; before the ice yielded to the resistance of the dolphin, it pressed it, as far as the eye could judge, about 18 inches out of the perpendicular, but as soon as the ice yielded it immediately recovered its upright position; and thus it continued, alternately being pressed and rebounding, for about 10 minutes, when a stoppage of the ice again took place.

As soon as practicable, the dolphin was examined, and the piles found, owing probably to the precaution mentioned above, not to have risen in the least; but that they had a lurch, or inclination towards the lower end and the Buda shore, of about one foot.

The pressure of the ice seemed to act in a direction quite contrary to expectation, inasmuch as the line of greatest pressure was supposed to act in, or nearly, the direction of the current; experience, however, proved that, in this case, the supposition was incorrect, the pressure being much greater in a diagonal direction, and towards Buda; and the reason appeared to be as follows.

On the Buda side of the dolphin are many warm springs, which, during a frost, are scarcely felt, but which, acting in conjunction with the warm weather which had preceded the moving of the ice, tended materially to weaken the ice on that side; and as the ice on the Pesth side, owing to the absence of springs, had stood quite firm, the effect of it in pushing the piles towards Buda will be perceived, the inclination towards that side being, indeed, much greater towards that side than down stream. When, however, owing to the floods from Upper Austria, the ice moves, the contrary is the case, as the stream, after passing Margarethen Island, sets in towards Pesth.

As the result of this experience seemed to prove that the base of the dolphin was not wide enough in proportion, piles were driven

all round at an angle of three feet in ten, and bolted and secured in the strongest manner to the dolphin.

On the 11th of March, the whole body of ice began to move, and after progressing for about five minutes, came to a stand above the dolphin and No. 1 dam, the remainder of the river being quite clear as far as the Blocksburg: shortly afterwards, the ice again made a movement, and formed a heap four or five feet higher than the top of the piles.

After the ice had got fairly in motion, and attained the velocity of the current, the noise and uproar of the immense masses, cracking and crashing against one another, and against the dolphin and dam, was tremendous, and altogether formed a scene it would be difficult to describe; sometimes a stoppage would take place, owing to the accumulation of ice between the dolphin and the dam, which kept that above back, until a mass of ice, more resembling an island than anything else it can be compared to, would force everything before it, breaking up the large blocks accumulated at the dam into a thousand pieces.

Considerable excitement prevailed at Buda, Pesth, and even at Vienna, owing to the different opinions as to whether the dolphin was sufficiently powerful to resist the pressure it was subjected to, and heavy bets were laid on the issue. The result, however, was most satisfactory; for, with the exception of the fender-piles, which were somewhat worn and damaged by the ice, not the slightest harm was done either to the dolphin or the dam.

A few days previous to the breaking up of the ice, it became evident that a considerable washing away of the gravel, by the action of the current, had taken place on the two upper sides of the dolphin. It was considered advisable, therefore, to sink a quantity of rubble stone, the same as that afterwards used inside the piers, where the washing away had afterwards taken place, and the event proved that this precaution was necessary.

On the 28th of March, 1841, the staging for driving the piles for No. 2 dam was commenced, and on the 1st of May the first pile was pitched. The average time of driving, including pitching, &c., was about 1½ day to each pile; the timber was excellent, and drove well.

The gravel was taken out at the head of No. 1 dam, and the excavated space filled with good puddle to a depth of 12 feet, and

the piles for the middle row were driven through the puddle into the clay. They drove well, averaging about one day to each pile, and were driven 6 or 7 feet into the clay.

An engine-house, engine, and pumps were erected to clear the dam of water; the site of the engine, and position of the sluices to let the water into the dam, whenever it should be necessary, either from the pressure of the ice around, or from other causes, will be seen on reference to the front and end views of the dam. (Plates XII. and XIII.)

In spite of the precaution of sinking a quantity of rubble stone as mentioned above, the scouring action of the water round the dolphin still partially continued, and the gravel thus washed away was deposited by the action of the current at the lower end, where the water was in many places seven to ten feet shallower than before the dolphin was commenced; to remedy this, a quantity of rock stone was brought to the spot in barges and sunk; 1170 yards cube were thus deposited at a cost of 2*s*. 6*d*. per yard.

The quarries of Sosküt, Waitzen, and Mauthausen were purchased by the Baron Sina, and worked under the direction of English foremen. The granite obtained from the latter was of most excellent quality, and of great size, and although there was at first much trouble in working the quarry satisfactorily, partly owing to the jealousy which the Germans entertained of the English quarrymen, and partly from the confined space in which work had to be carried on; yet as every stone got out enlarged the working space, this last objection soon disappeared.

The quarry at Waitzen (being 1200 feet above the Danube) was got into excellent working order before the autumn, and the stone found of very good quality and size; and considering the peculiar situation of, and bad roads leading to and from this quarry, the price at which it was delivered on the works, viz., 1s. per cubic foot, was considered very cheap.

The quarries at Sosküt were also during this year much extended and improved, and so arranged that an almost unlimited quantity could be obtained.

Experiments were made by Mr. Tierney Clark at Pesth, in the autumn, on bricks furnished by various makers, viz., from Steinberger of Pesth, Cseeky of Ofen, and the Geminde of Alt-Ofen. Of these Steinberger's stood A 1 on the list of experiments

whose bricks were better made, and the clay more uniformly mixed than the other samples; his price was 16 florins (32*s.*) per thousand, which was considerably higher than was expected; the price eventually came down to 12 florins (24*s.*) per thousand, and again rose in consequence of the great demand to 15 florins (30*s.*), which was the price paid up to the last; the size of these bricks was $12 \times 6 \times 2\frac{1}{2}$.

EXPERIMENTS ON BRICKS.

NAME OF THE MAKER.	No. of Samples.	Weight of an English cubic foot in lb.		Increase of Weight in an English cubic foot.	Began to Fracture with a weight of	Crushing-weight.
		Dry.	Wet.		lb.	lb.
I. Steinbergen, Pesth . .	1	66·82	83·28	16·46	375·	1617
" " . . .	2	73·41	87·49	14·08	248·7	3188
II. Csecky, Buda . . .	1	89·46	104· 7	15·24	1600·	1926
" " . . .	2	76·23	90·77	14·54	468·	1320
III. Christ, Buda . . .	1	78·03	90·81	12·78	937·	1237
" " . . .	2	77·9	90·96	15·06	1087·	1712
IV. Lechner, Pesth . .	1	71·77	92·06	20·29	400·	775
" " . . .	2	91·88	117·88	26·	1375·	2012
V. Gunsberg, Raab . .	1	70·94	88·89	17·95	375·	500
" " . . .	2	70·8	89·16	18·36	737·	1047
VI. The Town of Old Buda .	1	81·37	92·87	11·5	1400·	2266

All the quantities in English Measure.

It was found by no means easy to obtain a suitable lime for hydraulic purposes, almost all the samples slaking with great difficulty; the Styrian lime, in particular, would scarcely slake at all. The common lime of the country slakes nearly the same as the English, and is of good quality, as is proved by the buildings at Pesth, many of which are coated with it, and resist the effects of the atmosphere for many years.

After considerable trouble and anxiety, an excellent lime-stone was eventually obtained from near Peterwarden, on the Servian frontier. It being feared that if the stone was burned, and ground on the spot, it would often be damaged and spoiled, in consequence of the distance it had to be conveyed, viz., by water, all against the stream, 200 miles to Pesth, Mr. Tierney Clark

determined to have it burned on the works, in a flare-kiln, and then reduced by an edge-stone mortar-mill. The district from which the most excellent lime-stone was procured belonged to a monastery; the abbot of which, hearing it was to be used in building a national work, and one of so great advantage and utility to his country, called on Mr. T. Clark and expressed himself greatly pleased in being able to forward such an object, and would accept of no payment for the stone; the carriage therefore to Pesth was the only expense until delivered on the ground. Several experiments were made with this lime to test its fitness for hydraulic purposes, and a mass of brick and rubble-work was prepared and laid under water; after a short time it was taken up, when it was found that the mortar had set so firmly that it was the hardest part of the mass.

The piles at the lower end of No. 2 dam drove considerably harder than those at the upper; but still the difference between the driving of No. 1 and No. 2 was very great; to give some idea of this, it may be mentioned that the number of piles damaged and re-drawn in the former was, on the average, about thirty-eight per cent., while in the latter it was about seven per cent.

A twenty-five horse engine and pumps arrived in the autumn for the purpose of clearing No. 2 dam of water, and was fixed on the dolphin. (Plate XII.)

1842. The last piles for both dams were pitched just before Christmas, and by the 3rd of January the puddle was got into No. 1 dam as high all round as the middle walings (Plates V. and VI.), when the frost put a stop to the operation. On the 10th of January the pumps were got to work, although with considerable difficulty, owing to the frost, and in eight hours the water in the dam was pumped out down to five feet below zero. As soon as practicable, a well was sunk down into the clay in order the better to keep the dam free of water. During the excavation, the reason why the piles drove so hard, when just about to enter the clay, became apparent. Immediately above the clay, and in such intimate connexion that it seemed almost to form a part of it, was found a thick crust of stone, from 6 to 12 inches, the surface of which was very irregular, but smooth, as if worn so by the attrition of the large gravel and stones in immediate contact with it.

The pumps continued to work well in spite of the severe frost,

the little water which found its way into the dam had from 6 to 7 degrees of warmth (Reaum.); this, when there was 16 degrees of cold in the air, seemed not a little extraordinary, and is to be attributed to the fact that the leakage was mostly at the back of the dam, and in the same stratum as the wells at Pesth; the water from which was always about 2 degrees warmer than that in the dam, whilst the water in the Danube, 10 feet below the surface, was just about freezing point.

By March, the whole of the ground inside the dam had been excavated, and it was found that the superstratum of sand was of so soft and yielding a nature as to require to be entirely removed down to the stone-crust overlying the clay, and the excavated space filled in with concrete. During the excavation, it became apparent that the whole of the piles forming the inside row were more or less shattered at the bottom; in consequence of which a fourth tier of walings was fixed all round the inside of the dam.

The first pile for No. 3 dam, on the Buda side, was pitched on the 8th of April. The piles at first went tolerably easy; but as the driving proceeded they took six or seven days to get down; and in consequence of the great time requisite to drive them home, 5 feet was settled on as the depth to which they should be driven into the clay in future.

From the first it was feared that this No. 3 dam would prove a source of great difficulty and annoyance, and the result fully justified the expectation. As the driving proceeded, the piles went with even greater difficulty than at first; often the operation took from twelve to fourteen days to each pile, which in many cases broke off short in the ground, and could not be withdrawn. To remedy this, the gravel was dredged out to the lowest practicable depth; and where the piles had broken off, or were otherwise considerably damaged, a second row was driven immediately behind the first.

The first pile for No. 4 dam was pitched on the 12th of May, 1842. The piles for the most part drove very well: the excavation was at the same time proceeded with. About 30,000 yards cube were necessary to be excavated from this dam.

Travelling crabs and framework were erected over Nos. 1 and 2 dams. On the 24th of August, 1842, the first stone was laid by

the Archduke Palatine, representing His Imperial Majesty of Austria.

On this occasion the Archduke Palatine invited the principal magnates of Hungary to dine with him previous to laying the foundation-stone; and Mr. T. Clark had the honour of being one of his guests. After the ceremony of the dinner, Field Marshal the Archduke Charles presented to Mr. Clark, in the name of his Imperial Majesty Ferdinand the First, Emperor of Austria and King of Hungary, a magnificent gold box, set with brilliants. In the centre of the lid was the initial F., in brilliants, surmounted by a wreath of the same, with large brilliants at each corner. The cortège then left the imperial palace, with an escort of the military, for the Cofferdam No. 1, a most imposing sight, from the variety of the rich costume of the magnates.

TRANSLATION OF THE DOCUMENT, IN THE HUNGARIAN LANGUAGE, PUT INTO THE FOUNDATION STONE OF PESTH SUSPENSION BRIDGE, ON THE 24TH OF AUGUST, 1842.

The idea of connecting the shores of the Danube between the towns Buda and Pesth by a permanent bridge was brought forward by Count Stephen Széchenyi: at first, in a private circle of some inhabitants of those towns and of the kingdom, afterwards before a society under the title of the "Buda-Pesth Bridge Society:" and he began to collect the data serving for this purpose. With the same intention he, together with Count George Andrasy, visited England in the year 1832, and they published, on their return, the information gained there, together with their own opinions, under the title of "Report of Count George Andrasy and Count Stephen Széchenyi, made to the Buda-Pesth Bridge Society on their return from abroad. Presburg, 1833." The subject, thus ripened and prepared, was at last brought before the Diet assembled at that time; where, it having been supported by his Imperial Royal Highness the Hereditary Archduke of Austria, Joseph Anthony John, the beloved respected Palatine and Governor of Hungary, and by the assembled States of the Realm, the xxvi. law-article (act) of the year 1836, was, with the sanction of his gloriously-reigning Apostolic Majesty King of Hungary, Ferdinand the Fifth, passed, by which act the erection of a permanent bridge between Buda and Pesth, through the medium of a shareholders' company, was granted; and for the realisation of the object, an imperial committee was appointed. Acting on this law—one of a new kind aiming at the benefit and ornament of the country—the Baron Simon George Sina made the proposition to build a suspension chain-bridge between Buda and

Pesth, at the expense of a shareholders' company, to be formed by him, and according to the design and under the direction of the English artist Mr. William Tierney Clark, and he closed a contract on this subject with the Diet Committee on the 27th of September, 1838, which contract was afterwards declared valid by the xxxix. article of 1840. The works, in consequence thereof, were begun about the end of October, 1839, have since that time proceeded without interruption, and

THE FOUNDATION-STONE

of this suspension bridge has, with the usual ceremonies, and in the presence of a numerous assemblage, been most kindly laid this day, the 24th of August, 1842, under the paternal reign of his glorious Majesty Ferdinand the First, Emperor of Austria, as King of Hungary the Fifth of his name, by his Imperial Highness Charles Lewis John Joseph Lawrence, hereditary Archduke of Austria, Knight of the Golden Fleece, Grand Cross of the Military Order of Maria Theresa, and first-class knight of several other illustrious orders, Governor and Captain-General of Bohemia, Imperial Field-Marshal-General, Proprietor of one Infantry and one Lancer Regiment, as representative of the highest person of his Imperial Reigning Majesty, most graciously appointed for this purpose. In remembrance whereof, this document and different coins of his Imperial Reigning Majesty Ferdinand the First, Emperor of Austria, as King of Hungary fifth of his name, have been put into the foundation stone.

The document had been signed by his Majesty the Emperor of Austria and King of Hungary, Ferdinand; and it was signed on the spot by the Archduke Charles, Archduke Joseph, Palatine of Hungary, the Archduchess Maria Dorothea, Prince Joseph, and Princess Elizabeth, the present high dignitaries of Hungary, Count Stephen Széchenyi, Baron George Sina, Baron John Sina, some chief magistrates of the county of Pesth, the principal engineer, William Tierney Clark, the General Secretary of the Buda-Pesth Suspension Bridge Company, Anthony Tasner, and some other present persons.

In pursuance of the plan agreed on, the dredging for No. 3 dam was carried on to the average depth of 44 feet from the top of the outer row of piles, leaving about 10 feet of gravel to drive through, and extra piles were driven where the gravel found its way between the piles, as well as where it was known the piles were not driven to the proper depth, or were broken or otherwise injured. As the gravel was dredged out to the above depth, the

inner and middle rows were driven, and a great part of them got down as was supposed to the requisite depth.

The work was carried on in the above manner until the 7th of November, when from the appearance of several piles which were pulled up, and from other causes, it became apparent that the outer row (Plate xv.) was in a much worse state than had been expected, and was almost a matter of certainty, that those piles which had taken 10 or 12 days to get down, were not driven to the proper depth by at least three or four feet, having upset or lost their points to that extent. There was likewise every reason to believe that many of them were broken or dangerously crippled; added to this, the Danube was rising, and at the late time of the year with winter rapidly approaching, the general appearance of the dam was anything but satisfactory.

Upon mature consideration, the only course appeared to be to drive a much greater number of piles than was at first calculated upon, and another complete row of piles was driven all round at intervals of 15 inches apart, and in some cases double and triple piles were driven during the progress of the dredging. At the commencement of the driving, a few were got down to the depth of 57 or 58 feet, being from three to four feet in the clay; but as the gravel began to get compressed, many of them would not penetrate more than 54 or 55 feet, the sharp angular gravel, overlying the clay, appearing to be compressed into a substance as hard as rock.

The piles in No. 4 coffer-dam drove far better, and the making of this dam was, in comparison, easy to No. 3; a wharf was made, and two cranes erected before the winter. During the process of puddling, however, between the first and inner rows of piles, a large piece of rock was found imbedded in the space between them, which it very nearly filled up, and precluded the driving of the middle row at that part. Nothing therefore remained but to fill in between the two rows with puddle. Before the magnitude of the rock was ascertained, every expedient was resorted to to get it up, but without the slightest success.

After the fourth course of stone was laid in No. 1 dam, bringing it up to zero, the ice put a stop to further progress, and the water was let in by the sluices shown in the views of the dam, in order to equalise the pressure within and without. In No. 2 dam, on the contrary, the ice not being nearly so massive, the pressure

against the dam was not so great, and the masonry was continued.

During the winter the excavation for No. 4 dam was carried on, and the framing for the travellers erected. This dam was almost water-tight, the only spot where any leak was apparent being close to the large mass of rock above mentioned; however, by fixing a fourth tier of walings as low as possible, and by the greatest care being taken to render that part as secure as possible by means of extra braces, &c., this leak was made of very little importance.

1843. The water rose very considerably during the winter and earlier part of the spring, and by washing away the bank where it came in contact with the piles, soon formed a passage large enough to fill the dam; this was remedied in a temporary manner by continuing the outer row of piles some distance into the bank, filling-in and backing-up the space outside with puddle; and to guard against anything of the kind for the future, when a leak might be of more consequence, half timber bay-piles were driven to fill up the space between the gauge-piles at the back of the dam, and then backed up with clay, so as completely to close the dam. A small high-pressure engine and pumps were erected to clear this dam of water, and worked well.

The water rose very considerably in the months of June and July, and attained the height of 14 feet 5 in. above zero, with a tremendous current. The pumps kept the water down in No. 2 dam, with the exception of one day; but in Nos. 1 and 4, the leakage greatly exceeded the power of the pumps, and the works were at a stand-still for some days. The current is always very rapid in the Danube, generally from 6 to 7 miles per hour.

This rise in the water threw No. 3 dam very much back, a great quantity of mud and silt being deposited in it, between the outer and middle rows of piles, owing to the Danube flowing over those two rows; this stopped the dredging to a considerable extent, and caused a great loss of time in finishing this troublesome dam.

The lower granite quarry at Mauthausen was also completely under water, and stopped work for some time; the loading-wharf was also under water, and prevented some stone which was greatly required being sent. This rise of the water, to be attributed to the melting of the snow on the mountains of Upper Austria, caused many serious accidents from some of the large country boats

breaking loose, and, besides doing other damage, carrying away part of the bridge of boats. Several market-boats were also upset, in one of which from seventeen to twenty persons perished.

In the course of the summer, three floods took place, causing considerable hindrance; and each time, depositing a quantity of silt and mud in Nos. 3 and 4 dams.

Mr. Tierney Clark proceeded to Pesth in the autumn of this year, and endeavoured, without success, to get an examination made of the state of the piles in the No. 3 dam; owing to the great depth of water, 50 feet, and the situation of the piles, the ordinary diving-bell could not be used. Some of the most experienced divers were sent for from the swimming-school, but, after several trials, they gave up the attempt, finding that they could not descend more than 25 feet; the pressure then being just supportable; accordingly, a diving-dress was ordered from England, and proved of the greatest utility throughout the work.

The first stone for No. 4 pier was laid by Mr. Tierney Clark on the 22nd of September.

During his stay at Pesth, Mr. Clark made a trial of two cast-iron beams for the roadway. They were made at Pesth, at the Walz-Muhle, a small foundry established by Count Széchenyi, and were submitted to the test of five tons, suspended in the centre; when the deflection, arising from the defective preparation of the iron, was so great as to destroy its elasticity; rendering the beams cast of such metal useless for the purposes intended. The pattern was then altered by increasing the depth to make up for the want of strength in the iron, and further improved by the addition of an admixture of old scrap iron. This third beam was then tested with the same weight as the others, and the deflection found to be not more than one half of the latter. This result, however, was attained by the addition of 5 cwt. to the weight of the beam: this was considered strong enough for all purposes. A great advantage resulted from this trial, inasmuch as it proved that the beams could be made in Hungary; whereas it was before feared they would have to be cast in England—a serious addition to time and expense.

On Mr. Clark's return to England, his first attention was given to provide for the manufacture of the chains. This very important part of the undertaking was performed by Messrs. Howard & Ravenhill of Rotherhithe.

No. 1 pier had by this time—namely, the date of Mr. Clark's leaving, in the beginning of October—been raised about 20 feet in height, and might have been raised considerably higher had there been a better supply of granite, which was in part prevented by the unfortunate circumstance of several vessels, having on board granite for the back of the fixture-pier, getting aground, and much time was in this manner lost.

No. 2 pier was raised still more, namely, about 21 feet high; the workmanship, equally with that of No. 1, being most excellent.

No. 3 coffer-dam, which under ordinary circumstances might have been finished by the autumn of this year, still gave a great deal of annoyance and trouble. All the gauge-piles were found to be in good condition, and many of them 6 to 7 feet in the clay; but the inner row was found sadly defective, and, although the dredging was carried on to the lowest practicable depth, still continued to drive with great difficulty, as above the clay there was, in addition to the gravel, a hard slaty incrustation, through which the piles had to be driven; and this, added to the great depth of water, formed an obstacle which was only overcome by the most unceasing exertions and by untiring energy and perseverance. In addition to the above-mentioned sources of difficulty, when the water rose the dredging had to be discontinued; and when it subsided, left a quantity of silt and gravel in the dam, and no sooner had this been cleared away than another flood rose producing the same results, and this happened three times. Another evil arising from the high water was, the washing away of the gravel round the outer row of piles; this, however, was remedied by throwing in a great quantity of rubble-stone and also bags of clay all round the dam, in order to keep the piles upright against the great weight of the mass of puddle between the rows. (See Plates IX. and X.)

The winter of 1843-1844 was fortunately mild; nevertheless it was considered expedient to load the piles of No. 3 dam with blocks of stone, to prevent any tendency to flotation consequent on the washing away of the gravel, as detailed above. In the following spring, the pumping-out of No. 3 dam was commenced. This succeeded better than was expected, though several leaks occurred, and also a blow of fine sand, which caused the puddle

between the piles to sink down considerably. The engine and pumps used for this dam were taken from No. 1.

1844. Mr. Clark arrived at Pesth in September, and in his report to the Baron G. S. Sina mentions the following progress as having taken place in the works since October, 1843.

No. 1 pier had been raised 18 feet since the last autumn; and confident expectations were entertained that, if the weather proved favourable, the pier might be raised up to the level of the roadway in the course of the season.

No. 2 pier had been raised about 21 feet since the last report. The materials and workmanship of both piers first-rate.

The whole of the season had been very unfavourable, from the constant high state of the water, for finishing No. 3 coffer-dam. Mr. Clark, on examination of the piles, found them generally in a very crippled state, and additional piles had to be driven, and extra bracings fixed for their support. This bracing being carried round most part of the dam, added considerably to its stability. The completion of the dam, however, had been delayed for some time owing to the sediment under the puddle running out between the defective piles into the dam. This occurred several times, each time bringing with it the sand that remained under the puddle, and which could not be entirely dredged out, as well as some of the puddle itself; and as this had to be cleared away each time before fresh operations could be commenced, this of course was a source of considerable delay; but when free from these accidents, the dam was so nearly water-tight, that a small hand-pump was sufficient to keep it dry.

The accident which occurred to No. 4 dam, as before mentioned, during the last autumn, had been repaired at a comparatively small expense, and made perfectly secure, and the masonry within raised 15 feet.

The Count Andrasy sent, while Mr. Clark was at Pesth, two roadway beams, cast from his own foundry, according to a pattern furnished him. These beams were subjected to the required test, and stood it extremely well; and at the request of the Count one was broken by a weight of fifteen tons suspended from its centre, the distance apart of the bearings being 26 feet 9½ inches. Some air-holes existed at the point of fracture, or probably it would have stood a much greater weight, as the iron was most excellent.

Mr. Clark also made several experiments upon iron-bars, furnished him by various parties in Austria. The bars were sand castings, one inch square, English measure, and three feet distance between the bearings. Those from a foundry belonging to Baron Rothschild, Count Andrasy's, and a specimen from the flour-mill established, like many other things of great utility, by Count Széchenyi, were found to be the best, the mean of the three experiments being 917·99 lb. per square inch.

EXPERIMENTS ON THE STRENGTH OF CAST-IRON BARS.

		lb.
7	bars from the Flour-Mill, on the average, broke with	867·81
2	Concordial	744·57
4	From the Foundry of Baron Rothschild (planed) .	1181·342
8	From ditto ditto (sand-castings)	981·18
3	From Hoffman Brothers	702·53
2	From Count Andrasy	904·08
26	Experiments.	

The piles for No. 3 dam continued to be driven where the dam was defective, on the Buda side, and the puddle to be rammed down by driving a piece of timber 30 to 40 feet into it; this plan was found exceedingly good. On the 4th of October the dam was pumped out, and the 7th and 8th tiers of walings finished; but, on the 12th, a leak broke out in the old place, on the Buda side, but after running for a few minutes, the puddle settled down, and stopped it again. On the next day it again broke out with great violence, and although the sluices were immediately opened, a great quantity of puddle came in before the dam could be filled, the Danube being rather low at the time, and the sluices half out of water. After driving a pile in the defective place, and making good the puddle, the water was again pumped out, and the dam remained tolerably tight till the 17th, when a serious leak again broke out in the same place; the water, however, this time, came in quite clear, without bringing any admixture of sand or puddle along with it, there being no appearance of its stopping. The sluices were again opened, and the dam filled, after which the clay was driven down as before, and two piles driven behind the outer

row, there being no appearance of any defect in the inner row where the water came in.

One of the long sheeting piles was also driven at the upper end of the dam; it went tolerably well till within about two feet of the clay, when it could be driven only a quarter of an inch at a blow, with a 20-feet fall, and when within a few inches of the clay, ceased going at all, and split at the top.

On the 18th the engines were again started, and on getting out the water sufficiently low, one of the *short* sheeting piles was driven at the side of the dam with a large wooden monkey, weighing a ton and a half, and found to go perceptibly better than the long one. When the point was one foot in the clay, it went three-eighths of an inch, with a 15-feet fall; this pile was got 3 feet 10 inches into the clay, and would have gone further, had not the upper part been crippled. This experiment showed the great advantage of this mode of driving short sheeting piles, instead of driving long ones, in the usual manner.

Owing to the sluices being half out of water when the dam (Plate xv.) was filled on the 13th, they were rendered comparatively useless, and had the leak been of more serious character, the consequences might have proved very disastrous; and as there was a probability of the Danube falling still lower, or even of having the sluices above water, some remedy was necessary; the following plan was therefore adopted:—

A few piles were driven at the lower end of the dam, and the space they enclosed filled in with puddle to the depth of about 9 feet, so as to form a water-tight bottom above the rubble, and an open box with a loose bottom sunk some distance into it, and on this the sluice was fixed. This box was screwed down upon the puddle by jacks, to prevent the pressure of the water outside from blowing it up.

Two borings were made on the side of this dam at those points where the piles drove with such difficulty, and it was found in both instances, that the common gravel continued to within about two feet of the clay, where a layer of gravel was found, so hard that it was with the utmost difficulty that the auger could penetrate through it. This stratum seemed to be a kind of conglomerate or natural concrete.

As above mentioned, to prevent flotation, the dam was

loaded in the autumn with stone, leaving interstices between the stones by which the puddle might be renewed in case of need; the quantity of stone thus deposited on the dam was about 800 tons.

1845. In the following January the water having been, with some trouble, pumped out of the dam, an examination of the piles was made, and some few, which appeared broken or otherwise damaged, were re-drawn, and after getting up two from the lower, and three from the upper end of the dam, it was found that they had *all* lost their shoes, and to have their points staved up about 18 inches.

As the majority of the piles drawn since beginning to drive the sheet piling were found to be sound with the exception of their points, it was supposed that the seats of the shoes might be too small; some large, old, heavy shoes, with the seats 6 in. by 12 in., and weighing 110 lb. each, were altered so as to give them a blunter but stronger form, the sides of the shoe being rather convex; these were then tried, but after being driven within one or two feet of the clay, they were found to upset and give way as much as the others.

One of the piles on the Buda side of the dam was also drawn and found to have lost 9 *feet*, the stump having split all to pieces; yet this pile went regularly one inch every three blows for the last 6 or 7 feet.

Serious apprehensions were now entertained as to whether *any* of the piles had gone down to the requisite depth, and to set this at rest, the pile No. 4 on the Pesth side of the dam being, in the opinion of all on the spot the best, was drawn; however, it appeared that this was very little better than the rest, being found to be no less than 4 feet 9 inches short, the points of the stump having penetrated about 15 inches into the clay, as a small portion was found between the crevices.

Two of the best pieces of timber in the yard were now prepared, as a last trial of the possibility of driving the sheet-piling through the existing gravel into the clay. These piles were shod with a strong cast-iron shoe or socket, with a driving-seat nearly equal to the entire cross-section of the timber. One of these was driven until apparently 8 inches in the clay; on being drawn, its shoe was found gone, but the point upset about 2 inches only, being

in other respects quite perfect; the other pile, shod at the *butt-end*, was drawn when apparently 16 inches in the clay, when it began to split badly at the top, and found to be quite perfect at the point although the shoe was gone; showing the great difference in the gravel as to density and compactness.

As soon after the above particulars as the ice would permit, a well was sunk in the middle of the dam; at first, fine angular gravel continued without intermission until within about two feet of the clay, when a stratum of a coarser kind made its appearance, but even this was not particularly hard; but just before coming to the clay a quantity of flat, round stones, of about 15 or 18 inches diameter made their appearance, forming a pretty evident reason why the points of the piles were so damaged. The clay itself was found extremely hard and compact, and gave promise of a most excellent foundation, in case the difficulty of driving the piles was surmounted.

The severe frost (9° to 10° Reaum.) which now succeeded, put a stop for a time to further operations; the whole dam being one mass of ice, produced a most strange and picturesque appearance, every pile and beam being also encrusted thickly with ice, and covered with icicles of the most fantastic shapes, which formed as the water left them.

As soon as the weather permitted, a plan which had been under consideration for some time was adopted, viz., of driving half piles (8″ × 15″ or 17″) by a ringing engine or monkey, of five cwt., the jar caused by which was so little, that the dam could be kept clear of water during the operation, which was found quite impossible during the driving of the large piles; this plan possessed the additional advantage of allowing the middle space to be excavated during the driving, and then filled in with rubble the requisite height; by this means, also, the gravel could be moved in short lengths, and otherwise loosened so as to facilitate the descent of the piles.

The first piece of rubble-work was laid on the 3rd of March, by the Count Széchenyi, on the solid clay, and 220 men were kept constantly at work at this dam alone.

The plan adopted in driving the sheet piling to the dam was as follows:—The ground was removed about four feet deep, before a bay of piles was pitched; they were then driven as far as they

would go, about three or four feet, when the waling was fixed and strutted, and as much more of the gravel taken out, as left the points of the piles 18 inches or 2 feet in. (Plate XV.) A man was then employed with a kind of crowbar, with a spear-shaped head, about four inches broad, to stir up and loosen the gravel opposite the pile which was being driven; and in this manner the whole bay was got down to within a foot or 18 inches of the clay, when more of the gravel was taken out to allow of the lowest waling being fixed and properly braced, by the raking diagonal struts, up to the tier above them. After this waling had been secured, the gravel was further loosened, and the pile driven until it had penetrated from 9 inches to 2 feet 6 inches, and in some cases 3 feet in the clay. About two bays in length and one-and-a-half in breadth, were then cleared for building, and the rubble, composed of excellent soft gritstone, was then laid on the solid clay, and well grouted in.

In Mr. Clark's Report, dated from Pesth, whither he arrived in the beginning of August, to the Baron S. G. Sina, he gave the following account of progress made since last year:—

No. 1 pier was raised within two courses of stone of the carriage-way, or finished height, and a large portion of stonework was on the ground ready dressed for its completion.—Plate XXIII., &c.

No. 2 pier was raised considerably above the coffer-dam, and within one course of the level of the carriage-way.—Plates XVI. and XVII., &c.

No. 3 dam was, by the continued perseverance of Messrs. Adam Clarke and Teasdale, the senior and second clerks of the works, finished. The third course of stone was set, and the first five courses were expected to be finished before the winter closed in. All the men were kept at work till ten o'clock at night, and one gang all night, to unload the stone ready for the next day—a course productive of much saving in time, and but little additional expense.

No. 4 pier was also in a very satisfactory state, and confident hopes were entertained that by the next year the same progress would be made as by No. 1 in the present.

The winter of 1845-6 was more remarkable at Pesth for the unusually foggy and rainy weather which prevailed than for severe frost; and, in consequence, little progress was made during the

depth of the season, it not being possible to work more than eight hours per day. The first piece of granite parapet was finished in January; the cost of this first piece was 5*l.* 18*s.* 9*d.*, and, being fifteen feet long, nearly 8*s.* per running foot. The expense, however, was much heightened by the bad weather, and by being worked by day-work: subsequently the cost of granite, including *all* expenses, was three florins = 6*s.* per cubic foot.

The water stood uncommonly high during the winter and early part of the spring; on the average, 14 ft. 2 in. above zero, but with very little ice. During the continuance of the high water, the dams were kept constantly full by means of the sluices.

As before stated, the chains were made by Messrs. Howard & Ravenhill, of Rotherhithe, and cost 21*l.* per ton, exclusive of freight, &c. Gauges were made by Messrs. Troughton & Simms, in order to insure the greatest accuracy; the dimensions of the links, and their form, will be seen on reference to Plate XX. c, the retaining link and bar at Plate XXV. Machinery such as had never been in use before had to be made, for the manipulation of the chains, all of which was patented, as well as the manner of forming the links in the rough, which was quite new, and, in addition to being the best and most perfect mode, was by far the most economical.

The first delivery took place before the 2nd of October, 1846, according to the contract, and weekly shipments of about 15 tons took place, until the completion of the contract. The manufacture of the chains took place in the following order, viz.:—

1. The four bottom tunnel chains (Plate XXIII.)
2. The four curved links for retaining piers (Plate XXIII.)
3. The four curved links for towers (Plate XXI.)
4. The two top chains complete (Plate XI.)
5. The two bottom chains (Plate XI.)

The bed-plates and roller carriages (Plate XXI.) were made by Messrs. Hunter & English, of Bow, at a cost of 3000*l.* The blocks for hoisting the chains were manufactured by Messrs. Harvey, of the Hayle Foundry, Cornwall, and cost 750*l.* These blocks were the largest ever made, and the details of their construction will be seen on reference to Plate XXII.

Mr. Tierney Clark arrived at Pesth in July, and, in his annual

Report, gives the following account of the progress made since last year:—

No. 1 pier was completed so far as to be ready for the stone work for fixing the bed-plates at the head of the pier (Plate XXIII.), and the stones for that purpose were being quarried.

No. 4 pier was very nearly as forward as No. 1, and would be ready at the end of the season to receive the bed-plates and roller carriages, as well as the retaining plates, so that the chains might be fixed in the pier, as shown in Plate XXI., in readiness for their connection with the main chains.

No. 2 pier was finished to the height of the roadway, and both the granite plinths for forming the opening of the archway were set, as well as one course of stone above, and the last lift of the scaffolding (see Plates XII. and XIII.) was fixed at its proper height.

No. 3 pier had been raised 49 feet since the laying of the foundation on the 6th of July last year; there was, however, a great deal of masonry to be done on this pier before it would be ready for the reception of the roller carriages, and Mr. Clark gave instructions for the employment of more hard stone masons on this pier, and more granite masons were sent for from Italy.

The next point of serious consideration was the safest and most expeditious manner of hoisting the chains, and it is necessary to state that they were the heaviest ever attempted to be raised; the total weight of the centre chains alone, including tension-rods and blocks, exceeded 7940 cwts. = 440 tons. This weight will give some idea of the enormous strength necessary to be possessed by the machinery, as well as the necessity of having all parts of the very best materials and workmanship. The shafts and wheels to make the necessary connection with the 25-horse engine, for winding up the chain fall from the blocks, were made in Austria, but the chain fall itself, and blocks, were obliged to be made in England, and, as before stated, were manufactured by Messrs. Harvey.

The roadway beams and cantilevers were put in hand in the latter part of the autumn of this year, at the "Walz Muhle," and cost 12 florins per Vienna cwt.

The foundation for the wing-walls to the fixture piers was completed before the winter set in. Considerable difficulty was

experienced close to the dam piles outside, owing to the mud, &c., extending nearly down to the clay, it having filled in after the dredging for driving the piles there. (See Plate XXXII.) The season was very favourable for the completion of this wall. The depth of it averaged about 20 feet from the surface of the ground, except in that part where the mud, &c., had been deposited by the dredging, and the depth in this place, viz., close to the piles, was about 32 or 33 feet.

1847. The winter was a mild and very favourable one, and during its continuance the foundations for the wing walls on the Buda side were got in, and made rapid progress. As the inhabitants of Pesth, Buda, and indeed the whole country, were most anxious and impatient to push the progress of the work to the speediest completion possible, arrangements were made to meet this end. Before this period, night-work had, as far as possible, been avoided, and, in consequence, as the working space on Nos. 2 and 3 piers was so contracted, a limited number only of men could be employed on them, and the time of the setting machines was pretty nearly divided between *lifting* the stone, and *setting it* when raised; and, in order to enable the setters to be constantly occupied with their proper work, instead of being half their time in raising, the following plan was adopted with great success. The entire day was devoted to setting, and the night to lifting the stone, of course by separate gangs; and to prevent the blocking up of the working space by the quantity of stone, stages were erected over the pier at different heights, on which the stone was deposited during the night, and by these means the surface of the course in work was always kept free from incumbrance.

During this time a boring machine was being made at Pesth, for the purpose of boring out the recesses into which the retaining bars fitted (see Plate XXIV.), after the plates had been permanently fixed in their places, so as to insure the greatest possible accuracy.

The following work had been done, by the date of Mr. Clark's Report in September, 1847:—

No 1 retaining pier was finished, with the exception of the toll-houses and parapet walls. The stone for the toll-houses and pedestals was in part on the works, and the greater part of the granite for the parapet walls was already worked ready for setting.

This pier might have been quite finished by this time, but, as the other piers required all the attention and despatch possible, this part of the work was not pushed. The retaining plates were fixed and ready to receive the chains.

No. 2 pier was finished ready for receiving the chains, the masonry being raised to the level of the roller carriages, which were in the yard, and preparations being made for fixing them.

No. 3 was in so forward a state, by means of the great exertion that had been made, that in about a month it would be ready to receive the roller carriages, which were in readiness.

No. 4 pier was in the same state of forwardness as No. 1, the roller carriages were fixed, as well as the retaining plates, and the wing walls were in progress.

A great quantity of larch timber for the platform had arrived from the Styrian mountains, and was being prepared and dressed up for that purpose.

About 530 tons of links and bolts had been delivered, and another cargo expected shortly; about 79 cast-iron beams were in the yard, and in progress of being tested and examined.

Preparations were being made for raising the chains between Nos. 1 and 2 piers. The steam engine was fixed, and all other arrangements made for commencing operations as soon as the curved links, blocks, and falls arrived from England.

In order to arrive at the real average weight of the larch timber for the platform, 31 pieces of different scantlings and lengths were picked out, from 40 to 60 feet; these pieces were then carefully cubed and weighed, and the exact average weight per foot cube, was found to be 38·65 lb. The average weight of the white fir for the foot-path and nosing was 25·7 lb. per foot cube. The total quantity of timber in the middle openings was 19,857 cubic feet of larch, and 3,455 cubic feet of white fir.

1848. It had been originally proposed to raise the chains in the autumn of this year, that is to say, the backstay chains, or those between Nos. 1 and 2 piers (Plate VIII.), and this would undoubtedly have been done, had it not been for the great delay occasioned by the non-arrival of the iron work; and, owing to defective supervision, 200 tons had been suffered to accumulate at Frankfort, which should have been sent on to Pesth long before. The freezing of the Danube also delayed the carriage for some

weeks, and ultimately a portion had to proceed by land-carriage—a most expensive and uncertain mode of conveyance.

The towers were in readiness as well as the fixture piers, all having the roller frames and plates fixed ready for the reception of the chains, by the beginning of November; but, in consequence of the non-arrival of the iron-work, it was found impracticable to commence before the spring. The early part of the winter was, fortunately, tolerably mild; had it been severe, the result, as to the delay of the chains, &c., might have proved of serious inconvenience. In February, however, a great quantity of snow fell, and severe frost succeeded; and the ice, after continuing for a few weeks, broke up with great violence, about the middle of the month, and tore away a great portion of the round fender pieces of the dolphins above Nos. 2 and 3 piers, but did little or no damage to the framing itself. The gearing of the sluices of Nos. 1, 2, and 3, was likewise torn away, as, indeed, everything else which afforded the slightest projection for the ice to lay hold of. A great deal of damage was also done to the shipping and boats of the country, many of which were driven down the river, imbedded in the ice. The water rose greatly above, and did considerable damage to property: altogether, this was the severest break-up since the year 1838.

The first upper backstay chain was got up on the 28th of March, without the slightest difficulty; the blocks, crab, and gearing working extremely well. The position of the blocks, and process of hoisting the chains, will appear on reference to Plate VIII.

It was about this time that the first serious apprehensions were entertained concerning the state of political affairs in Hungary. A very strong party had been formed, who had for their object nothing less than a revolution in the government of Hungary, to make their country a separate and independent state, but *nominally* under the Emperor of Austria; and this party appeared to gain ground daily, and fears, which were afterwards realised, were entertained that this party would not separate until they had struck a blow somewhere. Just at this time, the most important part of the iron-work, viz., the chains, were on their road to Pesth, and had any occurrence taken place to stop them, the works would have come to an absolute stand-still. Luckily, the chains had all arrived before any violent outbreak occurred.

The Emperor and Court left Vienna in April. In Hungary, the Croatians were in open rebellion, and artillery, &c., were daily leaving Pesth, in steamers, for different posts up and down the Danube; and in the early part of May, the military came in contact with the populace of Buda, and several were killed. In order to assist their country in this critical situation, all the nobility and gentry delivered up their plate and other valuables to the government. The Count Széchenyi was one of the first to set the example of presenting nearly the whole of his magnificent service of plate, and others soon followed in proportion to their means.

In the beginning of June, there was an almost universal strike amongst the workmen in Pesth, and on the 8th a mob of about 1000 visited all the large establishments in and around Pesth, for the purpose of compelling the managers to employ none but Hungarian workmen, and to send away all foreigners. The Railway and Walz Muhle, probably intimidated by force, yielded, and made the required concessions, and signed a paper to that effect. The mob then came to the work-yard at the bridge, and reiterated their demands. Mr. Adam Clarke declined making any arrangement whatever with them, except what the constituted authorities ordered; and, whilst they were haranguing about "Freedom" and "Equality," sent off messengers to the magistracy and Chef de Police of the Minister of the Interior, and just as they were getting ready for mischief, Count Széchenyi made his appearance, and engaged their attention by giving them a speech in Hungarian until the guard, consisting of about sixty men belonging to the yard, armed with muskets and bayonets, got under arms, and showed a formidable front, which held the mob in check until the arrival of the Chef de Police, who ordered them to disperse, in the name of the law, which after a great deal of confusion they did, threatening, however, to come back again and set fire to the work-yard in four places.

The steamers were obliged to leave off running down the river, the whole population below Pesth being in open rebellion.

With the exception of stormy and angry meetings between the parties, the period which immediately followed was tolerably tranquil; the last parcel of iron-work arrived at the end of June, and the first centre chain (Plate VIII.) was hoisted and connected on the 8th of July, all the tackle working well.

In spite of the greatest exertion in finishing the works, the political state of the country was such as to furnish daily anticipations of their proceedings being stopped. The Minister of War and several of the Generals were killed near Vienna, and the city bombarded, the Emperor and Court left, and everything was in the greatest confusion; it was by the merest chance that the workmen were prevented from being sent off *en masse* to recruit the army. When the state of affairs, however, would allow of work at all, the roadway beams (Plate XXVI.) were fixed in their places, and the upper parts of the towers finished. The rosettes were of cast iron, made in Hungary, as were also the pedestals on the footway, round the towers (Plate XIX.), and the cantilevers for the support of the balcony had been previously made by the same manufacturer, and were already fixed in their places. All the ornamental stone-work was executed by German and Italian carvers; they worked very rapidly, and in first-rate style, some of them making upwards of a pound a day on No. 2 pier.

1849. In December the occupation of Pesth by the Imperial troops took place; and as the details of the war are still fresh in the memory of most, it will be needful here to give only a summary of them, in so far as they affected the bridge.

On the bridge of boats being taken out, about the 22nd of December, the provisional government took the management of the bridge into their own hands, allowing the officials, &c., to pass by tickets, and forbidding the public under the severest penalties to force a passage, the platform being by this time nearly completed, and already sufficient for a passage across.

This lasted a few days, till the "great and sovereign people," as they styled themselves, forced a passage, by tearing down the barriers, maltreating the watchmen, &c., and setting all rule and order at defiance; and for several days the bridge was constantly crowded with people passing and re-passing, from morning till night, the authorities making no further attempt to keep order.

The provisional government now sent messages to the directors of the bridge, to prepare the approaches, &c. for the passage of troops and cavalry, and afterwards likewise for artillery, and this to be done under the severest penalties. All representations of the danger which might occur from the passage of troops over an unfinished bridge, were unavailing, and totally disregarded. This

being the case, therefore, the 5-inch longitudinal larch timbers (Plate XXVI.) were covered over with cross temporary planking, to save them as much as possible. After this had been done, the bridge was daily crossed by infantry and cavalry regiments, light and heavy artillery, baggage waggons, &c., and the whole of the Hungarian army at last retreated over it, and on the 5th and 6th of January the Imperial troops, to the amount of about 70,000 men, comprising nearly a dozen cavalry regiments, and 270 cannon, passed over it, and took possession of Buda-Pesth.

Whenever it was at all practicable, the work was proceeded with, although of course but little could be done when the platform and approaches were covered all the day with military, stores, &c. The foundry, where all the ornamental work had been made, was taken possession of for military purposes, and M. Ganz himself was obliged to cast cannon for them; so that, for months together, hardly a casting found its way to the bridge. The foundry of the Walz-Muhle, where all the roadway beams and larger work had been cast, was also immediately shut up on the entrance of the Imperial troops. Some very large stones were brought from Soskût during the winter, in spite of the difficulties attending the journey; one of them contained 200 cubic feet English. This formed the head and shoulders of one of the lions on the Pesth side.

By the beginning of February the fortress of Buda was very strongly fortified, and several of the largest pieces of cannon planted, so as to sweep the platform of the bridge; a strong battery was also erected to defend the entrance.

About the 20th February, the General commanding the forces at Pesth issued an "ordre" that all workyards, shops, magazines, and materials of every kind whatsoever, that were on the Pesth side, should be pulled down and taken away before the night of the 11th of March at the latest, otherwise he should be compelled to resort to the most severe compulsory measures, and in that case that all compensation would be denied to the Company. By working day and night, however, this "ordre" was obeyed, and by the night of the 11th the ground round the bridge was as clear as if the workyard, &c., had never existed. The iron and machinery was taken to Buda, and the stone, timber, &c., all removed to a distance. Close to the bridge, and just about where

the engine for raising the chains stood, was built a military block-house for about 100 men, with blank walls pierced with holes for musketry—a dry ditch and palisading in front, and a covert-way for the passage of soldiers behind.

After the passage of the Imperial troops on the night of the 29th April over the suspension bridge and bridge of boats, the latter was set fire to and completely destroyed, being previously covered with pitch, tar, and other combustible matter. General Hentzi then caused the whole of the 5-inch platform timbers, as well as those forming the footpaths, to be cleared away, leaving the cast-iron beams and trussing between Nos. 3 and 4 piers standing quite bare. He then caused four large cases, containing about 30 cwt. of gunpowder, to be placed on the 13th and 14th beams—counting from No. 4—close to the chains, two on each side, with a train extending out to behind the toll-houses, with orders for the artillerymen to fire it if the Hungarians attempted to force a passage—Pesth being already in possession of the insurgent troops. All direct communication now ceased between the two towns, the shores of both sides the Danube being lined with hostile troops, who soon began to fire on each other with small arms. One could see the artillerymen in the fortress standing by the cannon with lighted matches, ready to fire at a moment's notice. There were about 100 cannon directed against Pesth, mostly 24-pounders, with 64 and 120-pound mortars. The Buda workyard was strongly fortified with palisades and cannon, and lined with troops. Matters continued much in this state till the 4th of May, when the Hungarian army under General Georgy, about 40,000 strong, made its appearance on the heights above Buda, and commenced bombarding the fortress.

As the Hungarians on the Pesth side had planted cannon above the bridge, and were making other preparations to attack the troops in the Buda yard, General Henzi commenced at about midday to bombard Pesth. The cannonade continued, with but little intermission, till about 12 o'clock at night; and Mr. Adam Clarke, who was an eye-witness of all that occurred, on going home to his quarters at the above time, found that a 24-pound shot had smashed everything in his bedroom, while several smaller ones had made great havoc in the other rooms. The fortress continued to be bombarded without intermission, day and night, by the

Hungarians till the 9th, and several attempts had been made without success to take the Buda yard and works by storm. On that day preparations were again made, but on a larger scale, to open a fire on the Buda yard from Pesth. In consequence of these preparations being observed from the fortress, a tremendous fire was opened on Pesth with shells and grape-shot; this lasted only an hour, but did immense damage and set fire to several houses.

The whole population of Pesth, with very few exceptions—of which Mr. Adam Clarke was one—fled into the country round about. The "Stadt Walchen" was quite an encampment of civilians, where about 80,000 inhabitants of Pesth, of all ages and ranks, were encamped in the open air,—while for the few who remained in the town it was a difficult matter to procure food, of even the coarsest description.

Up to this time, the bridge, as far as we could see, had suffered little or nothing. One of the $\frac{8}{4}$ columns of the lower toll-house on the Pesth side had been shattered by a shot, and some of the setting machinery damaged, but that was all. The Hungarians, however, had now got battering artillery from Comorn (which had fallen into their hands at the beginning of the outbreak), and were making sad havoc in the fortress—the whole of the heights from Blocksberg where the Observatory stands (see map) up to Altffen being covered with batteries playing day and night incessantly. This continued up to the evening of the ever-memorable 13th of May, when, as if to show that the previous firing had been mere child's play, General Hentzi opened such a fire of shot and shells on Pesth as will never be forgotten by those who witnessed it. From 7 o'clock in the evening till 12 midnight, balls, bombs, and rockets fell like a hurricane of fire over the devoted city; by 9 o'clock it was on fire in thirty-two different places—and the thunder of the cannon, the crashing and hissing sound of the shells as they fell in hundreds, and above all the roar of the flames, which seemed determined to leave not a vestige of poor Pesth standing, formed a scene to the senses impossible to be described.

The next morning the city, indeed, presented a sad sight. After the cannonade ceased, the progress of the flames had been stopped; but half the city appeared in ruins, the houses all more

or less injured from the shot, the glass from the windows filling the streets, and the pavement torn up by the shells. The town and fortress of Buda was also in much the same condition, great numbers of houses being burnt and destroyed, as well as the Palace of the Palatine, which burnt for four days and nights.

At last, on the night of the 20th of May, the walls of the city were stormed at all points by an overwhelming force; and after a bloody and severe struggle, in which General Hentzi lost his life, the fortress was taken; and on the morning of the 21st, the Hungarian colours appeared floating from the towers. Between 6 and 7 o'clock that morning, and after all was lost, with the exception of the Buda workyard, which was still held by the brave General who commanded them, he—for what reason is not known—set fire to the powder on the bridge with his own hands, blowing himself and about 80 feet of the skeleton of the platform to atoms; after this, all resistance ceased. Five of the beams were blown to pieces, and three were broken, but still hanging. The troops broke into the offices and magazines at the works, and destroyed much valuable property, and it was with the greatest difficulty that the papers and drawings were saved from destruction.

The Hungarian General Georgy now came and gave orders for the bridge to be repaired for the passage of troops; and as there were several spare beams in the yard, this was done in four or five days.

On examining the state of the bridge it appeared, that although many shot had struck the bridge, there was but *one* which had done damage of any consequence. This shot, a 24-pounder, and fired apparently from the Blocksberg, had unfortunately taken effect on one of the long-forged links which connected with the curved set of the upper chain on the Buda side (see Plate) of No. 3 pier; the ball struck the outer bar about 12 inches from the head, and forced it close up to the second bar, which, however, was unhurt; there were in the damaged bar several cracks or rents from the upper edge downwards, one of which cracks extended to the depth of 3 inches. It was almost impossible to replace the damaged link owing to its being one of a set of ten, thereby rendering it necessary to remove the outer links from each of the adjoining sets before the faulty link could be got

at; and one of the sets, as before stated, are the curved bars in the tower itself. The bar struck was reduced, as was supposed, about one half in strength, and the means adopted to remedy the accident will be hereafter stated.

The bridge continued open for the military and a part of the public till the 30th of May, when it was closed, and the works commenced again at all points; and as the authorities stated that the progress should not again be interrupted, a beginning was made to lay the wood pavement on the platform.

The works now proceeded for some time in quiet and good order, great difficulty being, however, experienced in procuring workmen, several thousands being employed in destroying the fortifications at Buda at very high wages. About the end of June, in consequence of the advance of the Imperial troops upon Raab, orders were again received to put the bridge in a state for the passage of troops and artillery; the work was therefore again, in great part, suspended, and the platform covered with temporary planking, to save the longitudinal timber as before.

On the 7th of June, after the insurgents had been beaten at Raab, the Polish General, Dembinsky, sent a detachment of sappers and miners, with pitch and other combustibles, to deposit them in such positions on the woodwork of the bridge as would insure its speedy and certain destruction, as soon as the retreating Hungarian army had passed over, in order to prevent the Imperial troops from following. In answer to the remonstrances of Mr. Adam Clarke, General Yörök said it was with a heavy heart he set about the destruction of such a work, but that his orders were imperative. Mr. Adam Clarke then went to General Dembinsky himself, and made a most energetic remonstrance, assuring him that the burning of the bridge was an unnecessary piece of vandalism, which would sully his name and reputation for ever, and that the bridge could soon be made impassable for four or five days, the longest period possible to prevent the crossing of the Imperial troops, as a ponton bridge could be thrown across in less than that time. At last the old General thought proper to listen to reason, and sent a detachment to assist and, if necessary, to compel the workmen to make the necessary preparations. All hands were now set to work to take the screws out of the beams, &c.; and the next day, Sunday the 8th, after the troops had

all passed over, the 5-inch timbers were again cleared away between Nos. 3 and 4 piers, with about 80 feet of the skeleton of the platform, and leaving an opening of that extent where the chains were the only communication. The beams and iron-work were lowered into two barges, which were scuttled and sent adrift.

The period at which it had been arranged that the opening of the bridge should, if possible, take place, was the 1st of March, 1849, and every exertion had been made with this intent; and from the great progress made in every part of the work, there can be no doubt that it would have been finished, that is to say, open for traffic, by, if not before, that time. The unfortunate occurrences which took place at the very period, in which a short continuance of the exertions, then being made, would have insured its speedy completion, of course prevented the bridge being opened either at that time or at any part of the summer. For months the bridge, its works, and magazines were in use for military purposes. Well and bravely, in the opinion of all, it sustained the severe ordeal to which it was exposed, and great was the admiration expressed of it by all who witnessed the occurrences at Pesth, where it was popularly styled "the eighth wonder of the world."

During the war the bridge had been tested by the passage of numerous troops of the different armies of infantry, cavalry, and artillery, with heavy waggons and the usual accompaniments crowding the entire surface of the platform, not only for a day, but for weeks together, day and night, and this when the trussing and bracing, which adds so much to the strength of the platform, was for the most part not erected.

Mr. Tierney Clark made his annual visit to Pesth in the autumn of this year, and after a close examination of the entire structure, found that the bridge had sustained no damage whatever, with the exception of the link before mentioned in one of the top chains. After consideration, Mr. Clark came to the conclusion, that as great delay and expense must result if the damaged link were removed, the best plan would be to fix a thin link beside the damaged one, and also another on the opposite side, the section of these additional links together being greater than the damaged one. To replace the link would have occasioned great expense, whereas the two additional thin bars cost only 10*l.* 4*s.* On

Mr. Clark's arrival on the 21st of September, the state of the works was as follows, viz.:—

The entire platform, carriage and footways, were finished ready for traffic; the toll-houses also perfected. The lamps and pedestal for the toll-gates (Plate XXXVI.), as originally intended, were fixed; but Mr. T. Clark, fearing that on some occasions accidents might occur, altered the position to that shown in Plate XXXII.; it was in the first instance fixed between the toll-houses, as in most similar structures. The lamp and pedestal at end of wing-wall (Plate XXXVII.) was also fixed, as well as the majority of those on the pedestals round the galleries or balconies round the towers (Plate XVIII.), for foot passengers. The fence separating the foot and carriage ways, from the head of the retaining pier to the toll-houses, was in a state of forwardness, but not finished, being delayed for the want of castings and smith's work, owing to the late disturbances. The carriage road on the Buda side had yet to be made by the town authorities, according to agreement, as also that on the Pesth side.

There were, besides, other works to be finished, in no way interfering with the traffic on the bridge, before it could be considered completed. No. 1 cofferdam was nearly down; No. 2 in progress; and No. 3 could not be taken away until the concrete and rubble work between the water and inner rows of piles had been put in. No. 4 dam had been entirely taken away.

The bridge was opened for general traffic on the 20th of November, 1849.

Thus was finished Pesth Suspension Bridge, a work which, in its construction, encountered probably more difficulties than any structure of a similar kind in existence. The magnitude of the river over which it is thrown, its depth, nature of bed, and velocity of current, created the misgivings, at one time almost universal in Hungary, that no permanent communication could ever be established across the Danube between Buda and Pesth. The moral difficulties to be overcome, no less than the physical obstacles, were very great. Pride, prejudice, and jealousy had each to be encountered, so universal against the object at one period, that nothing less than the extraordinary energy and perseverance shown by Count Széchenyi could have withstood their evil effects, and few would have made the attempt.

The benefits derived from its construction are incalculable: two cities of great size, opulence, and resources have, by its means, been brought into immediate connection, where before existed only an uncertain, and occasionally perilous, means of communication—not to speak of the great addition made to their attractions by the suspension bridge as a structure of art. Good will no doubt accrue by the increased means of transit, and consequently further and extended commerce. Hungary is gradually becoming more known and appreciated, and with much advantage to the development of her natural resources. By increased intercourse with other nations, her inhabitants may be infused with more energy and less prejudice, while the good and sterling qualities possessed by many of her principal men, as by the great and good Count Széchenyi, will be discovered and admired. He is now, alas, it is to be feared, morally lost to his country and friends for ever; but his great labours for the advantage of Hungary remain, and their good effect is becoming daily more perceptible.

ADDITIONAL PARTICULARS.

The total cost of the bridge up to the end of December, 1849, including everything, excepting the expense of taking tolls, lighting, and watching, was 6,220,428 florins sterling (622,042*l.*) Interest and purchase of land amounted to 1,519,294 florins (151,929*l.*) The old materials and machinery valued at about 100,000 florins (10,000*l.*)—giving the total cost of the bridge itself 4,601,134 florins (460,113*l.*)

The greatest observed difference in the versed sine of the chains of the centre opening was 14$\frac{3}{4}$ inches; the greatest degree of cold at which observations could be taken was 20 degrees below zero, and the greatest heat 34 degrees above (Reaumur)—leaving a difference of 54 degrees.

The prices paid for the different kinds of labour were as follows:—

The wages of labourers at the commencement of the work varied from 28 to 32 kreutzers per day; they eventually rose to 34 and 40 kreutzers.

	At the commencement	At the end.
Carpenters and bricklayers . .	40 to 48 krs.	50 krs. to 1 fl. 15 krs.
Italian carpenters	2 fls. 0 krs.	1 fl. 20 krs.
Stone masons	1 fl. 20 „	1 fl. 40 krs. to 2 fls.
Granite masons	1 „ 40 „	2 fls.
Pattern makers	1 „ 0 „	1 fl. 20 krs.
Setters	1 „ 15 „	2 fls.
Smiths, firemen, etc. . . .	1 „ 20 „	1 fl. 40 krs. to 2 fls.
Hammer-men	0 „ 50 „	1 fl. 5 krs.
Fitters	1 „ 20 „	1 fl. 40 krs. 2 fls.
Boat and bargemen . . .	0 „ 50 „	1 fl. 6 krs.

[The above prices refer to a day of ten hours.]

THE PRICE OF BUILDING MATERIALS, ETC., AS FOLLOWS:

(ALL DELIVERED ON THE WORKS.)

	fls.	krs.
Fifteen-inch square baulk timbers, in length from 40 to 80 ft., per foot run . . . . . 30 krs. to	0	40
Oak, same lengths and size . . . . . 1 fl. to	0	50
Square larch in lengths from 40 to 60 ft.	2	0
Round do. do. per cubic foot	1	0
Common round timbers, 50 ft. long, and averaging 12 inches at the butt . . . . . each	3	0
Ditto do. 60 ft. long, and averaging 18 to 20 inch. at the butt . . . . . 16 fls. to	18	0
[This applies to the timber from Austria and Bavaria. The Hungarian timber from the Waag being of much inferior quality, cost 25 to 30 per cent less.]		
Four-inch. planks 18 ft. long, 12 inch. broad (Bavarian) . each	1	36
Three ditto ditto ditto . „	1	12
Inch boards ditto ditto . . „	0	30
Rubble stone per cubic klafter (216 feet)	8	0
Granite, including all expenses	3	0
Sand, fine and free from impurities, per cubic klafter . . .	12	0
Gravel, best 8fls. Ditto, got by dredging, per klafter . . .	4	0
Hydraulic lime, ground for use, per cubic foot.	0	50
Coal for smiths, per Vienna centner	0	40
Charcoal, per Vienna metizen	0	24
Coal for steam-engines, per centner	0	24
Hard Soskût stone, per cube foot	0	40
Soft ditto ditto	0	30
Waitzen ditto ditto	0	34

[The above are the averages including all expenses.]

Waitzen quarry was distant 25 English miles.

Sosküt quarry was distant 16 English miles.

Mauthausen granite quarry was distant 270 English miles.

No. 1 dam was commenced and the first pile was pitched on the 28th July, 1840; finished August 6th, 1842.

No. 2 dam was commenced and the first pile pitched May 1st, 1841; finished August 6th, 1842.

No. 3 dam was commenced and first pile pitched April 8th, 1842; finished April 4th, 1845.

No. 4 dam was commenced and first pile pitched May 12th, 1842; finished January 5th, 1844.

The following is the number of piles in each dam, and the per-centage drawn and re-driven:—

No. 1 dam, 1868 pitched, 509 drawn=38 per cent. drawn and re-driven.(?) This large per-centage is accounted for by the fact that a large quantity of the oak timber just procured proved unfit for driving.

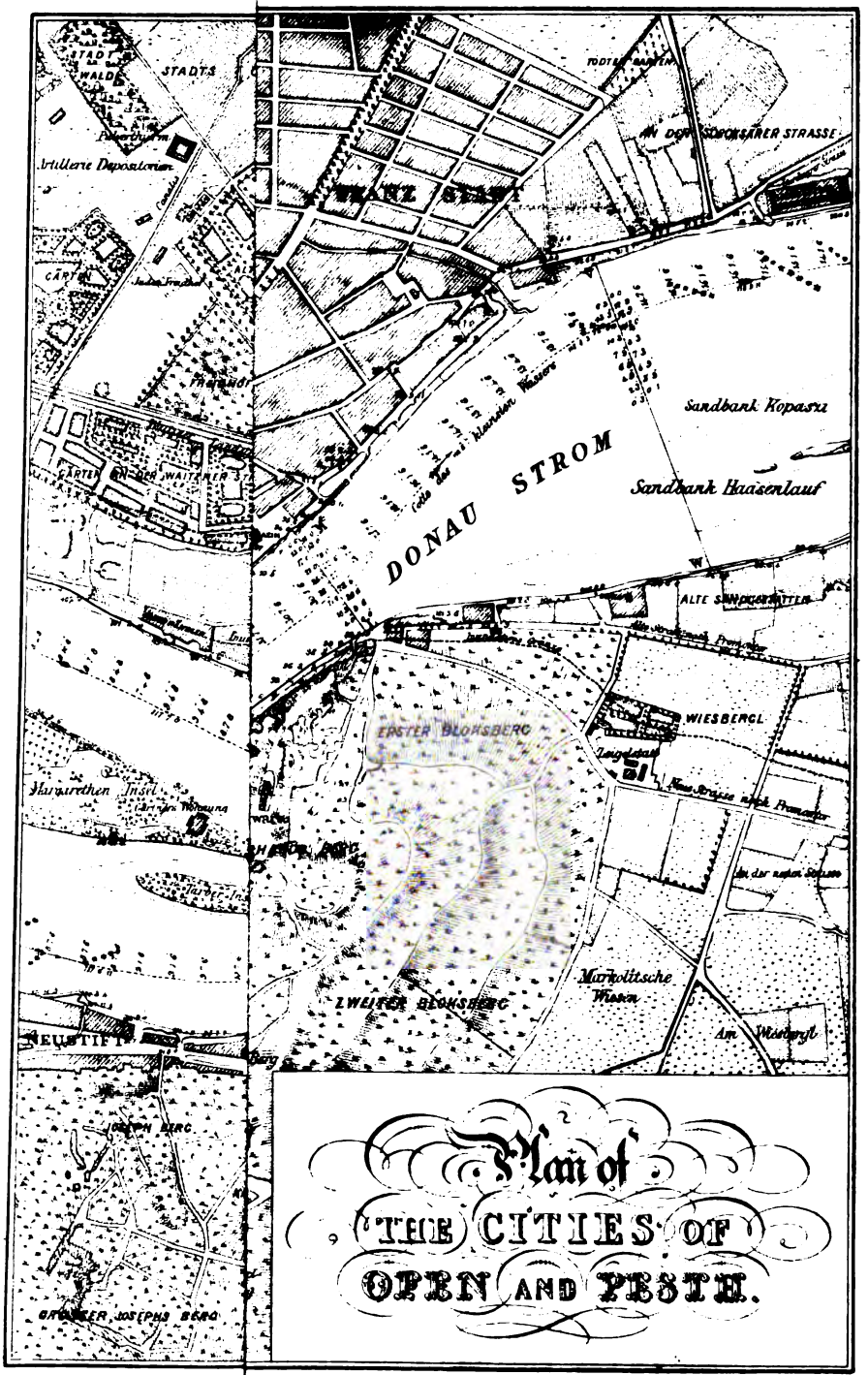
No. 2 dam 1100 pitched, 77 drawn—7 per cent. drawn and re-driven.

No. 3 dam, 1227 pitched, 174 drawn—16½ per cent. drawn and re-driven.

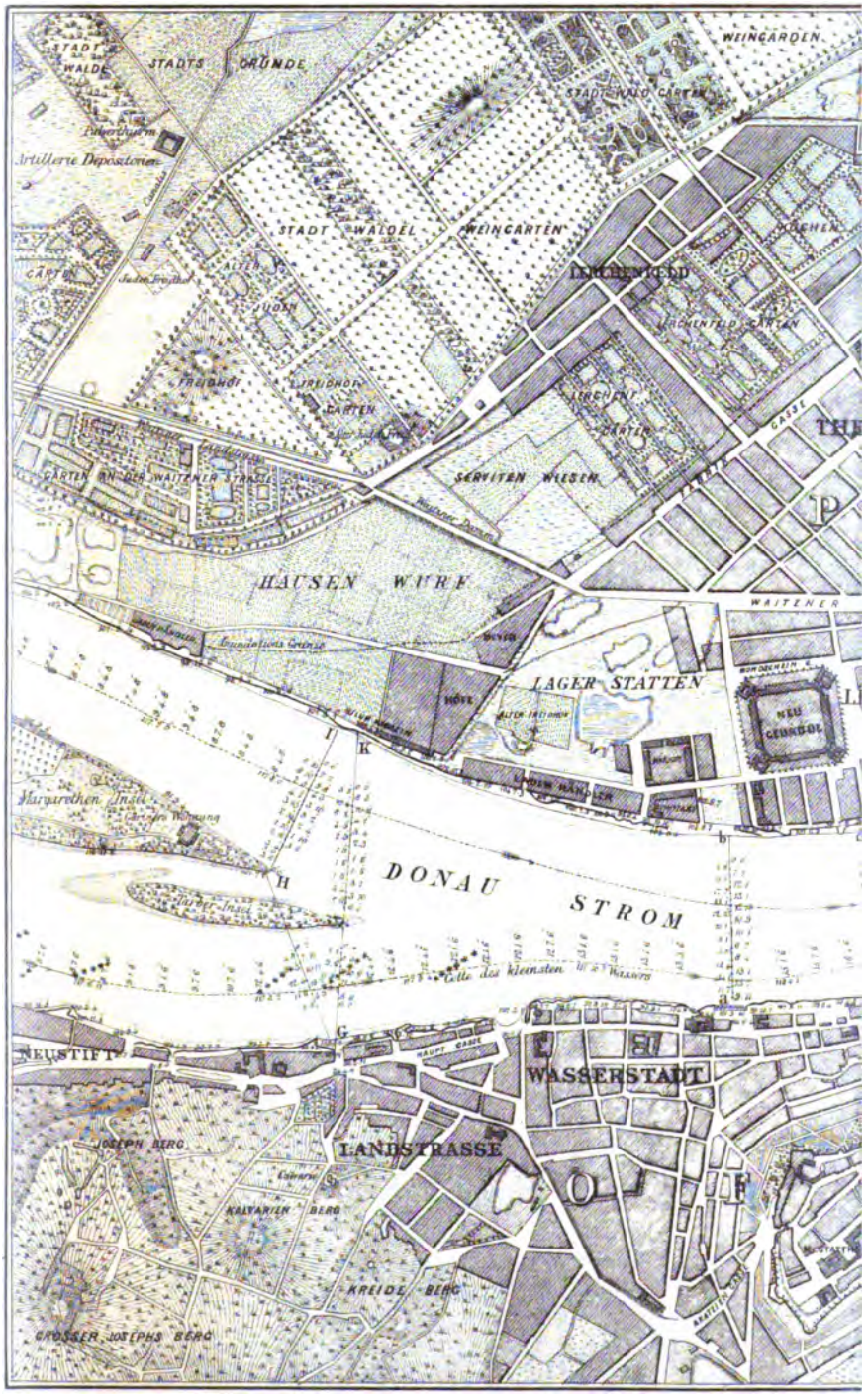
No. 4 dam, 1029 pitched, 32 drawn; about 3 per cent. drawn and re-driven.

THE END.

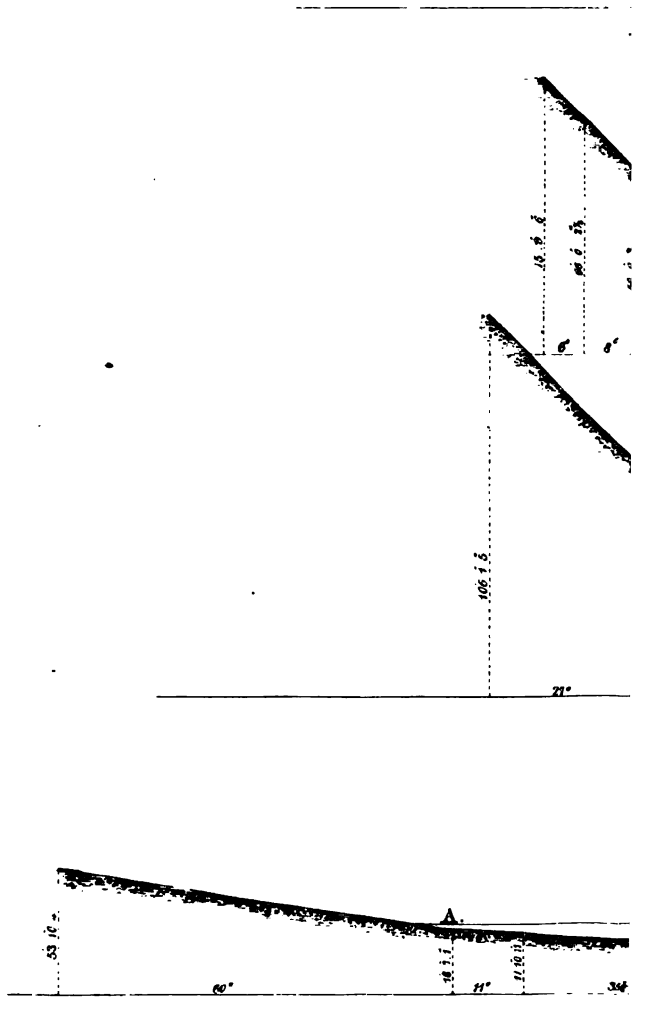
BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.



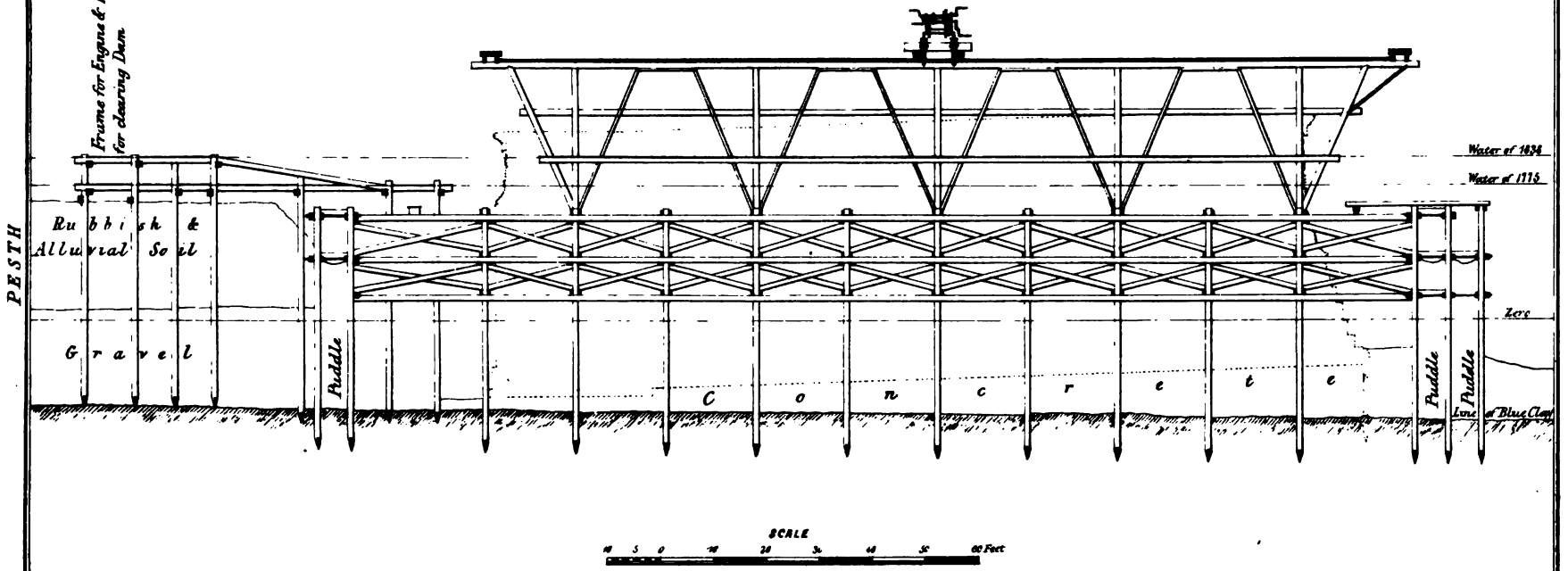
Plan of THE CITIES OF OFEN AND PESTH.


STADT WALDE
STADTS GRÜNDE
WEINGARTEN
STADT WALD GÄRTEN
Artillerie Depositorien
STADT WALDEL
WEINGARTEN
HOCHEIM
LERCHENFELD
LERCHENFELD GÄRTEN
FREIHOF
FREIHOF GÄRTEN
KIRCHEN
KIRCHEN GÄRTEN
GÄRTEN AN DER WAITZNER STRASSE
SERVITEN WIESEN
HAUSEN WIRT
WAITZNER
LAGER STATTEN
NEU GEINBOL
Margarethen Insel
DONAU STROM
NEUSTIFT
HAUPT GASSE
WASSERSTADT
JOSEPH BERG
LANDSTRASSE
KALVARIEN BERG
KREIDE BERG
GROSSER JOSEPHS BERG

Sections and Soundings of River Dan
referred to on Plan N°1.



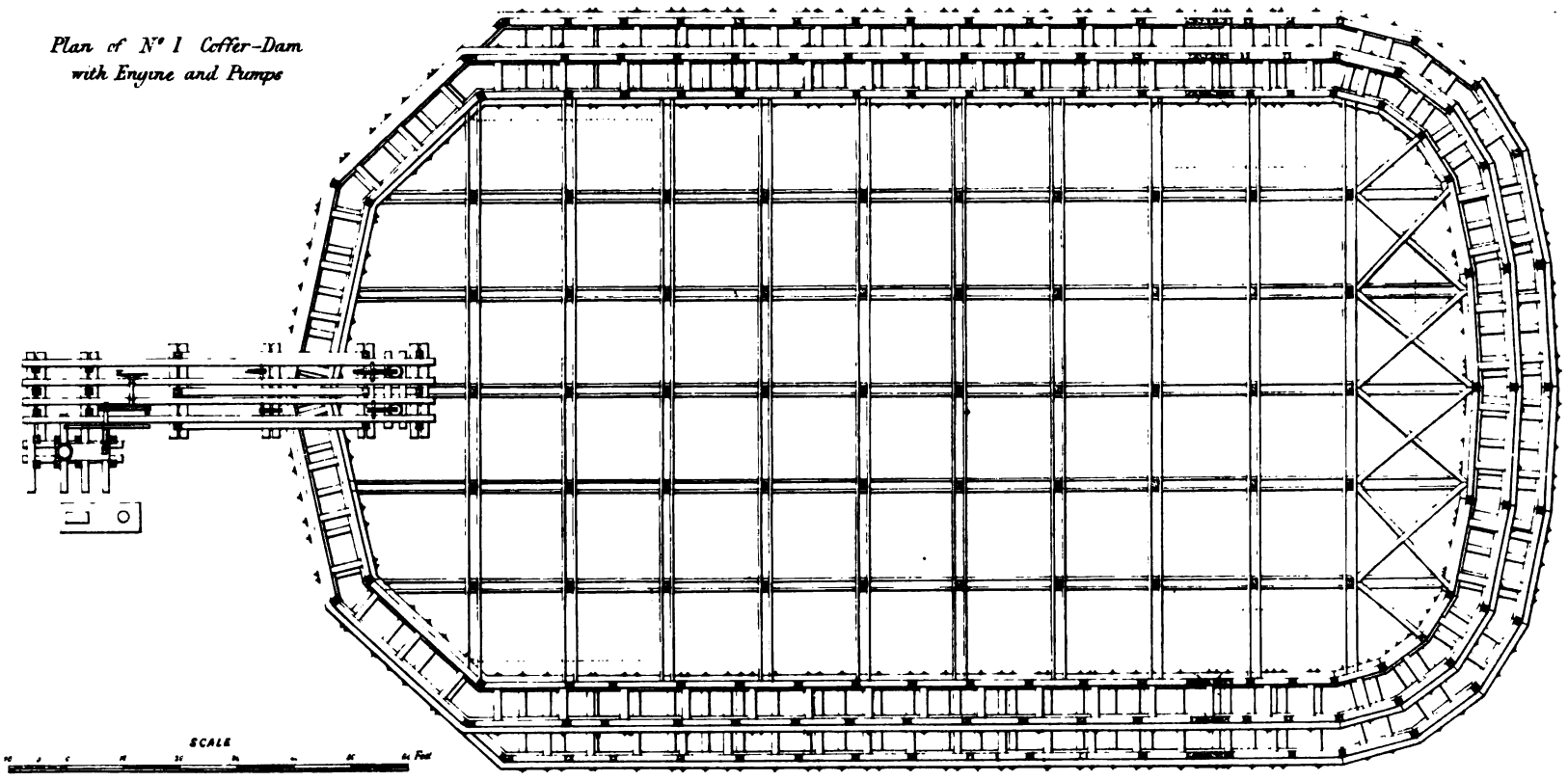
Longitudinal Section of Framing of Nos 1 & 4 Coffer-Dams for Fixture-Piers with Traveller for raising Stone.



Pl. 3.

Published by John Weale, London. May 1st 1862.

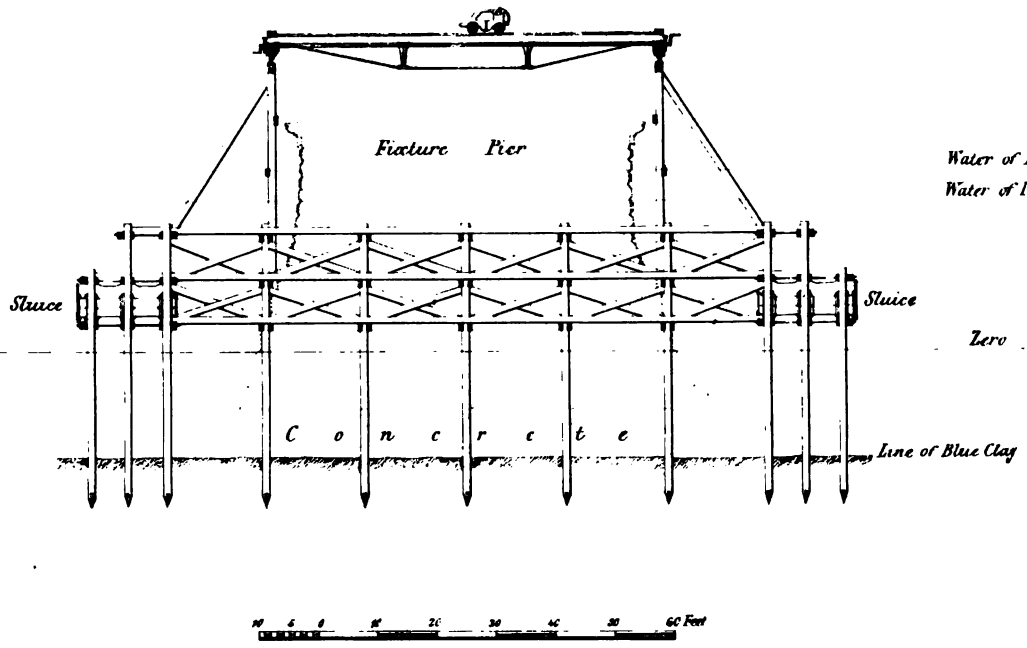
Plan of N° 1 Coffer-Dam with Engine and Pumps



Pl. 4.

Published by John Weale London. May 1st 1862

End View of Fixture Piers
with
Transverse Section of Framing of Coffer-Dams for Nos 1 & 4

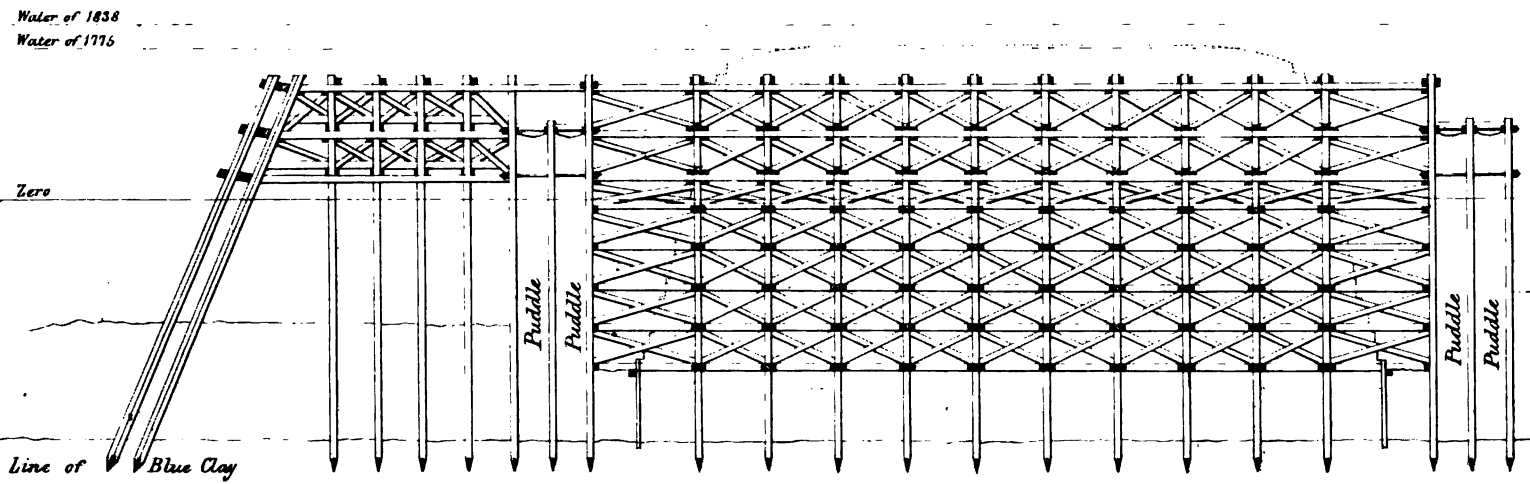


Pl. 5

Standidge & Co. Lithrs London

Published by John Weale London. May 1st 1842.

Longitudinal Section of Nos 2 & 3 Coffer Dam and Ice-Breaker.



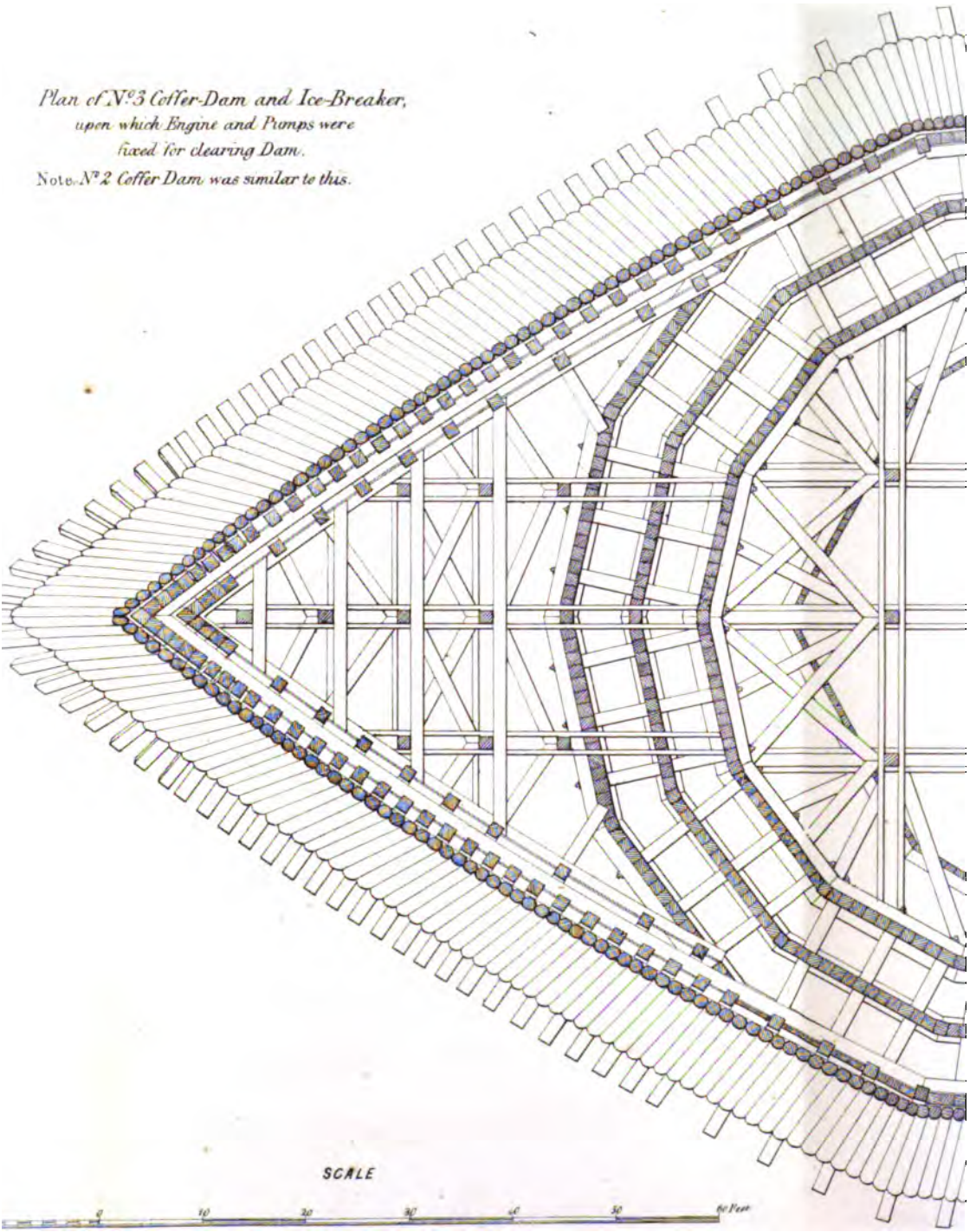
SCALE.

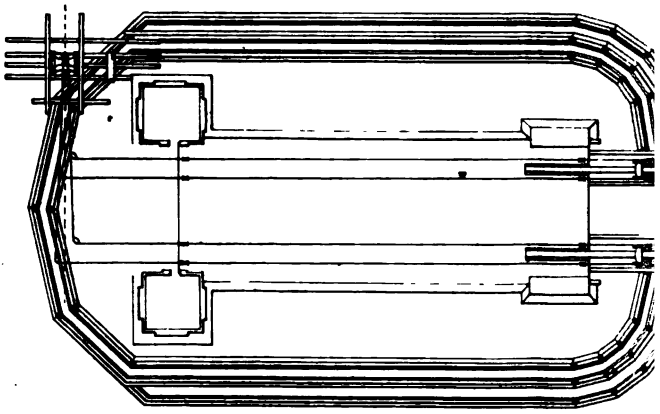
0 5 10 20 30 40 50 60 70 Feet

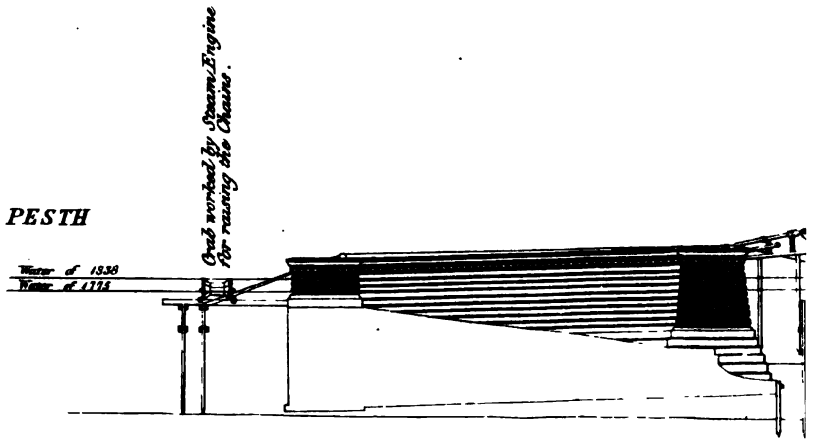
Standidge & Co Lithe London

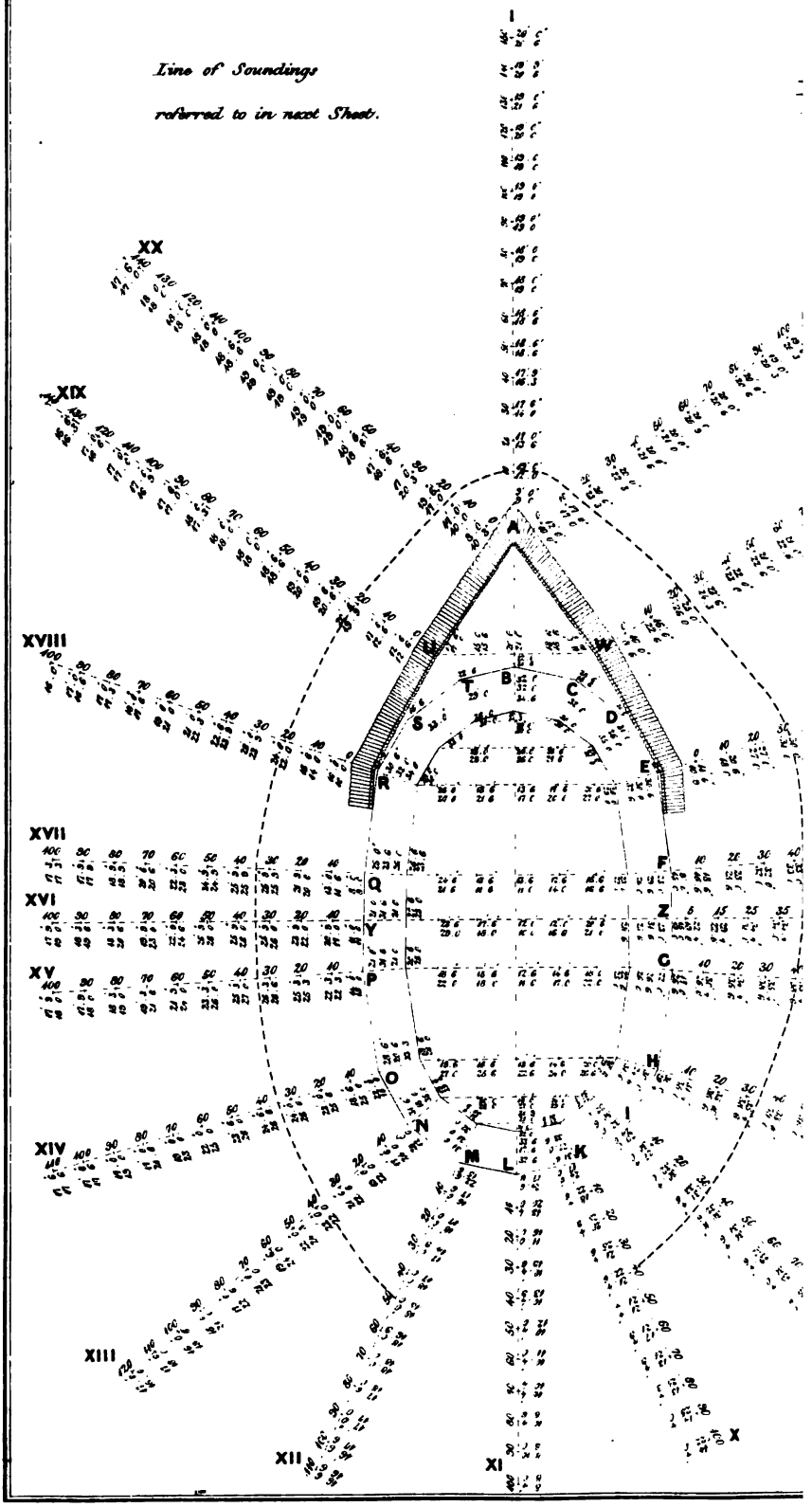
Pl. 6

Plan of N°3 Coffer-Dam and Ice-Breaker,
upon which Engine and Pumps were
fixed for clearing Dam.
Note. *N°2 Coffer Dam was similar to this.*






PESTH
Water of 1838
Water of 1775
Crab worked by Steam Engine for raising the Chains.


Line of Soundings
referred to in next Sheet.
I
XX
XIX
XVIII
XVII
XVI
XV
XIV
XIII
XII
XI
X
A
B
C
D
E
F
G
H
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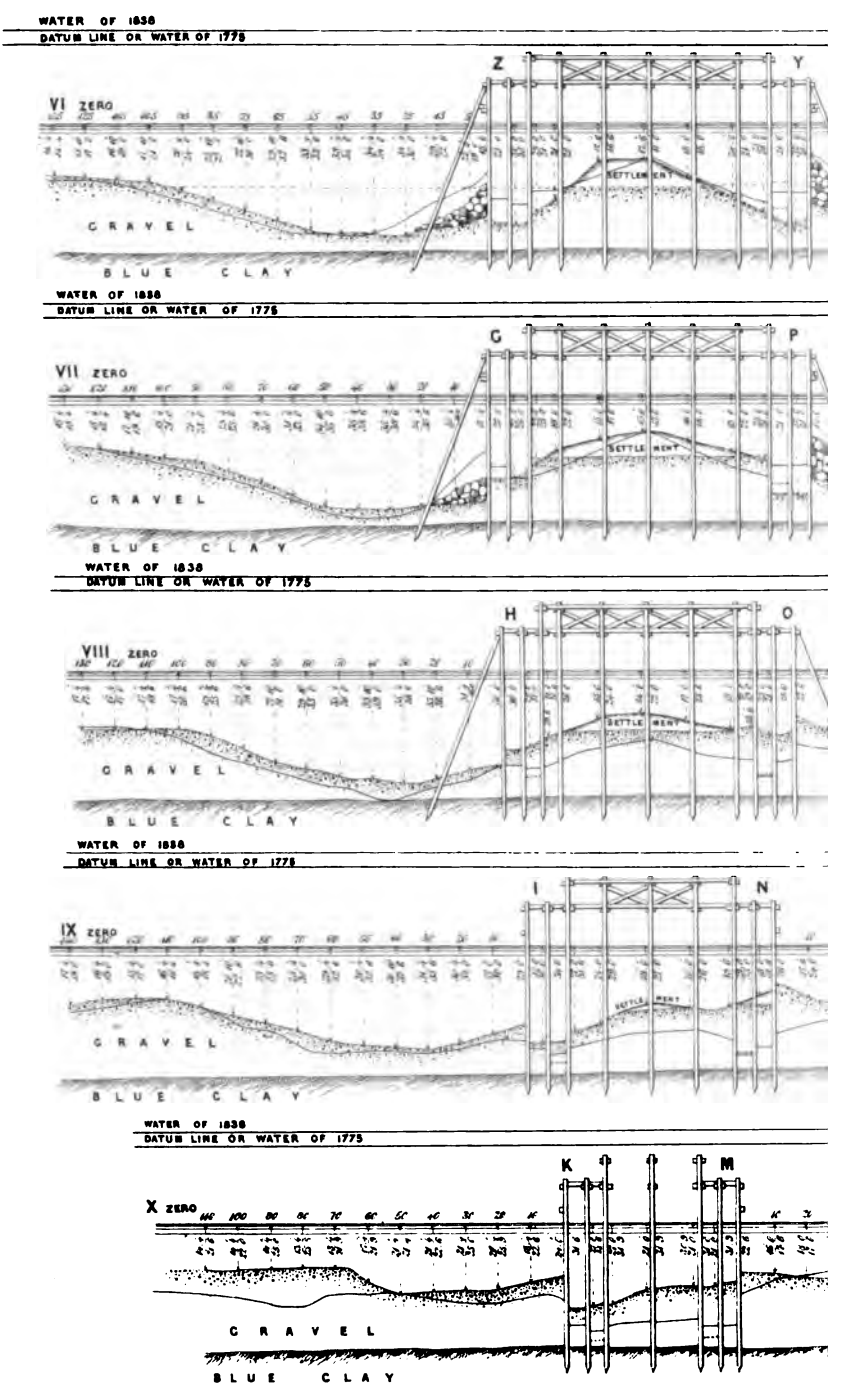
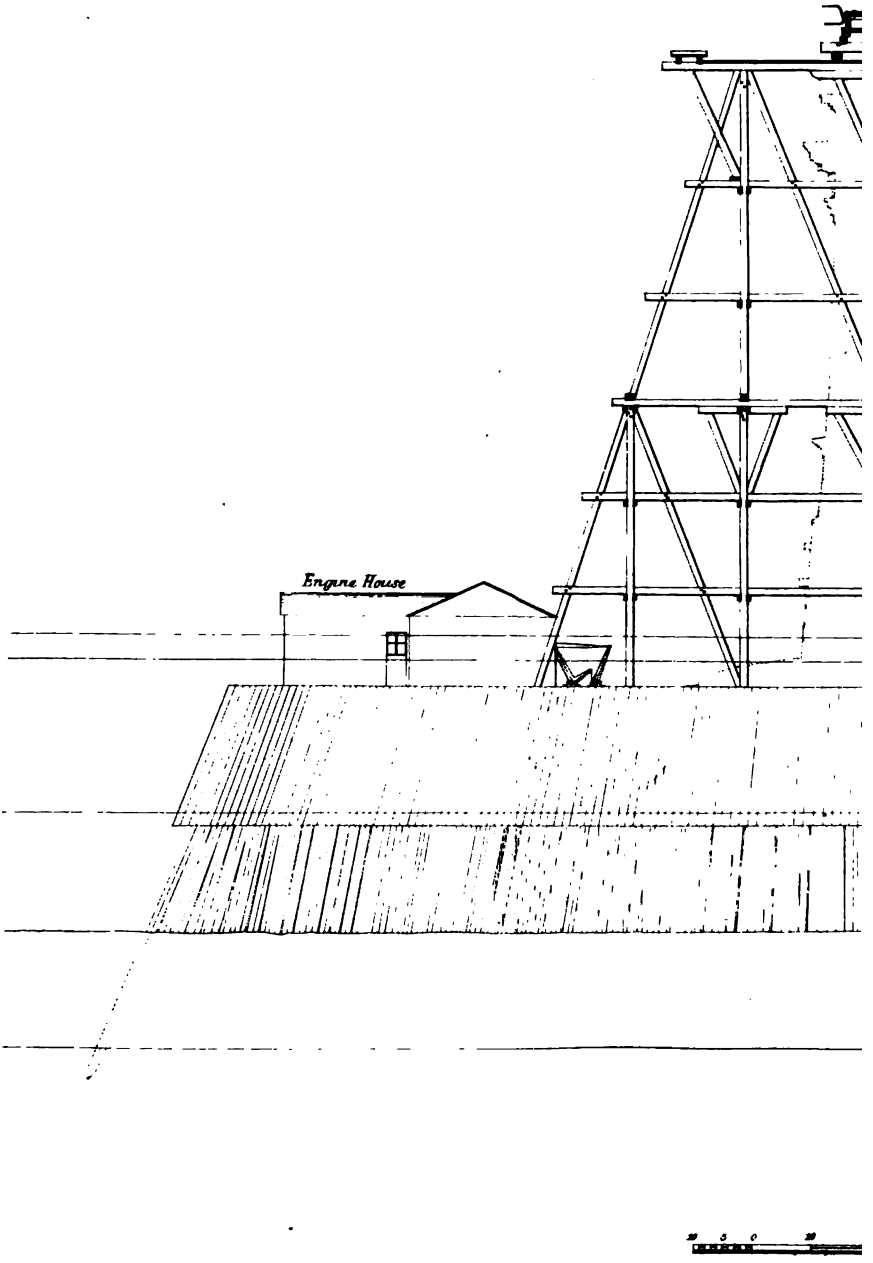
U
W
Y
Z

N°3, Dam, Transverse Section.

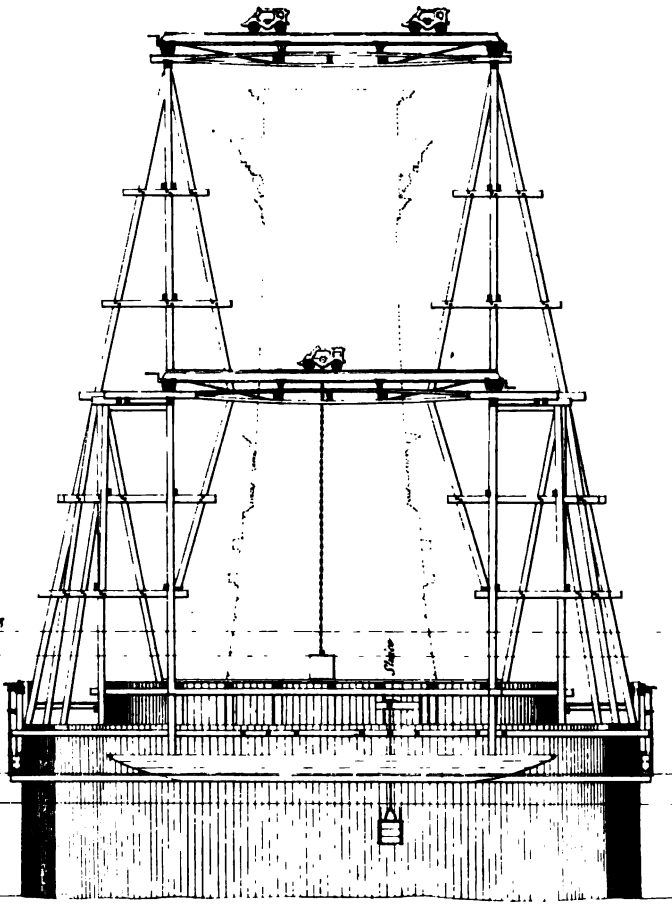


Elevation of N.os 2 & 3 Coffer
for raising



Published by John

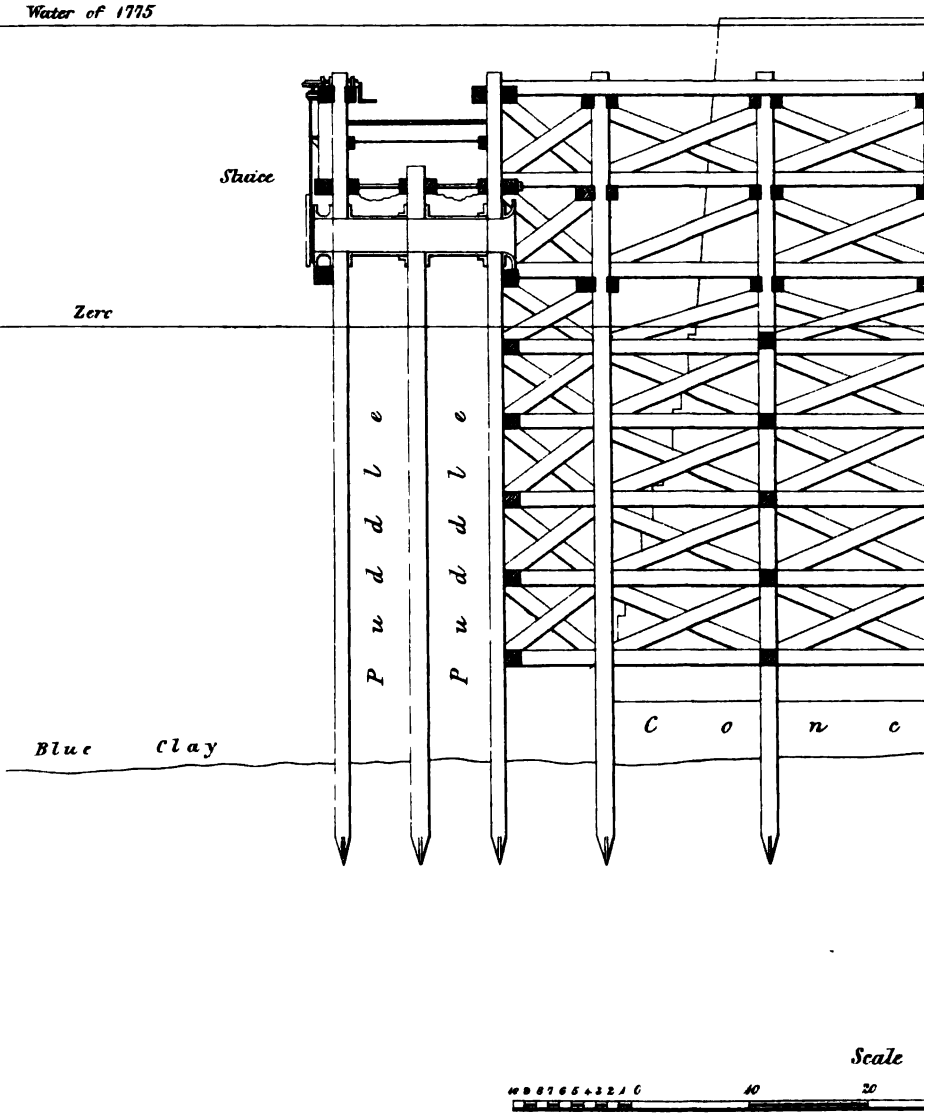
End View of Nos 2 and 3 Coffer Dams, with Framing and Travellers, for raising and setting Stone.



Standidge & Co Lithrs London.

Published by John Weale, London, May 1st 1844.

Transverse Section.

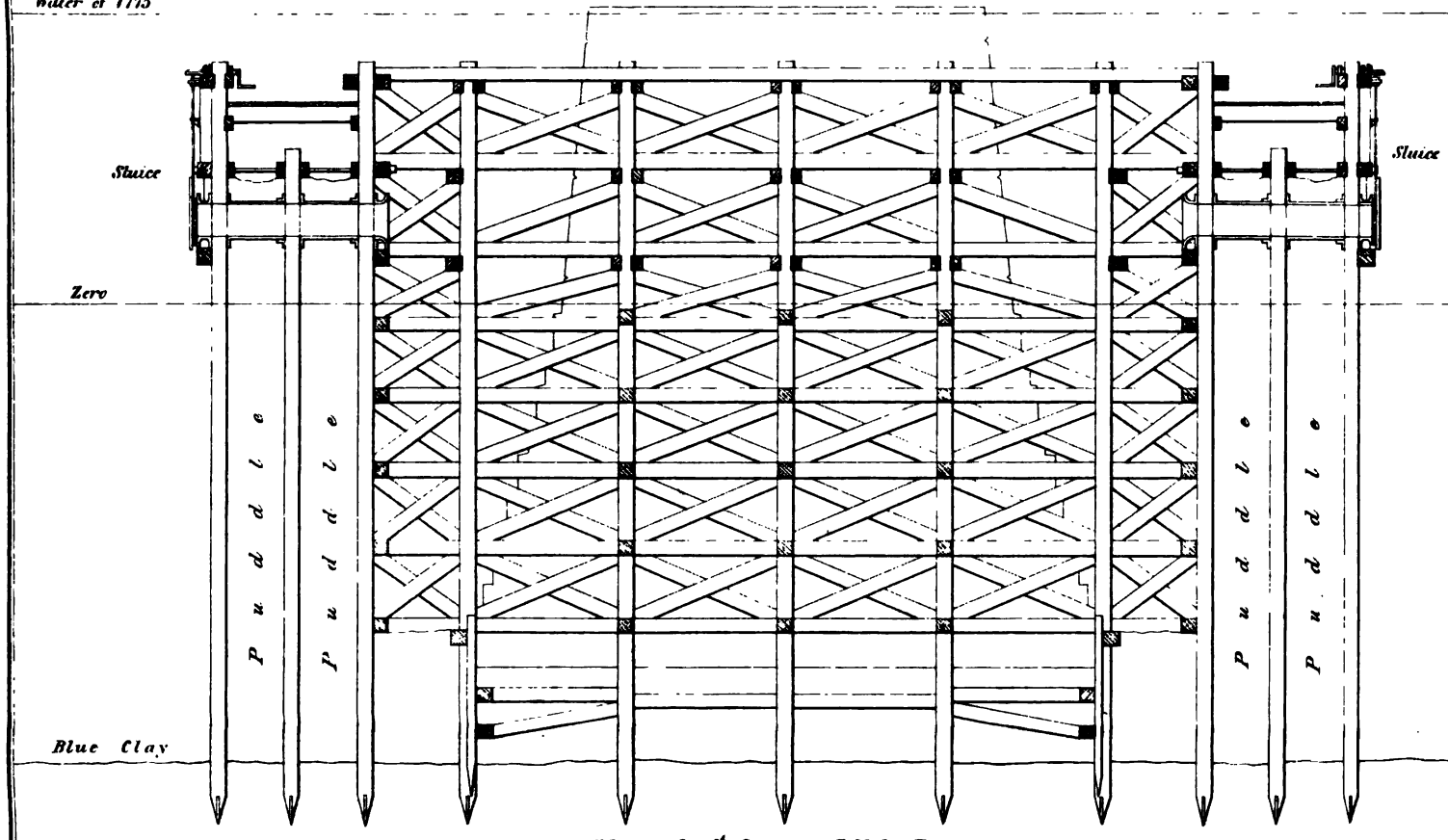


Scale

40 20

Published by John Weale

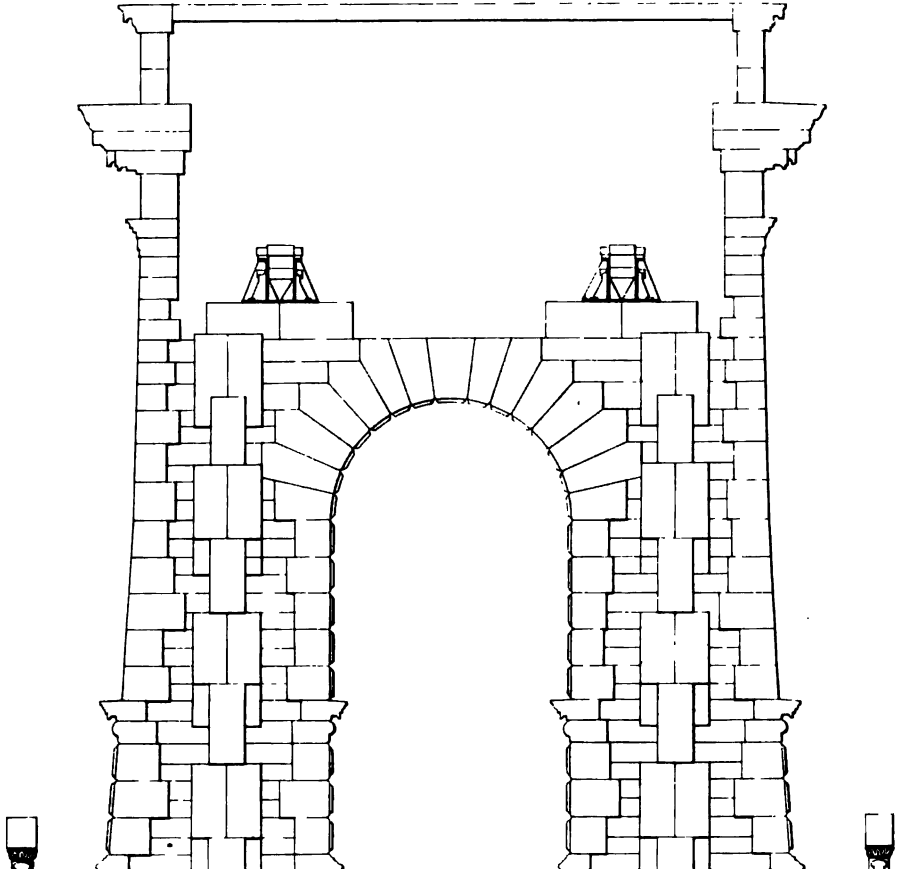
Transverse Section, N.º 3, Cellar Dam.



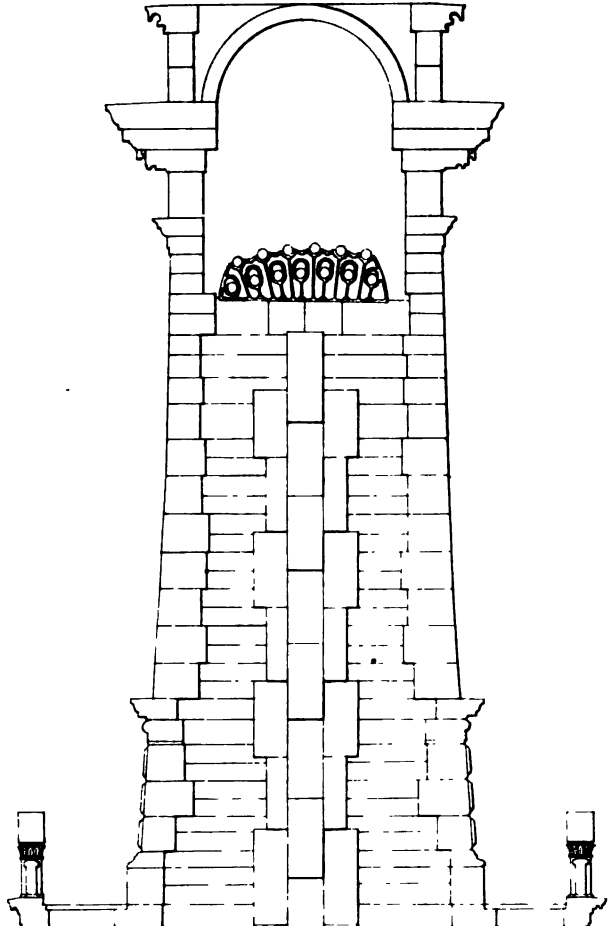
Plan of 1st Course, N.º 3, Pier.

VERTICAL SECTION OF Nos 2 AND 3 PIERS

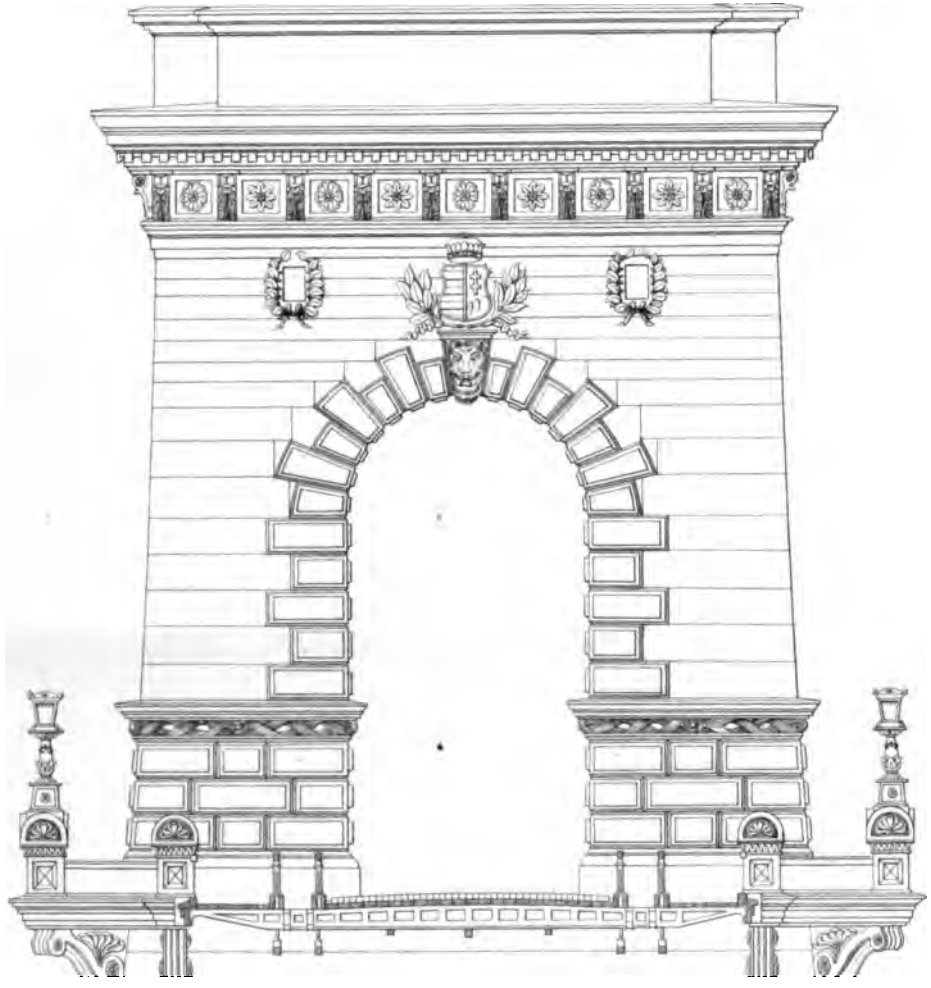
SHEWING VERTICAL BOND-STONES.



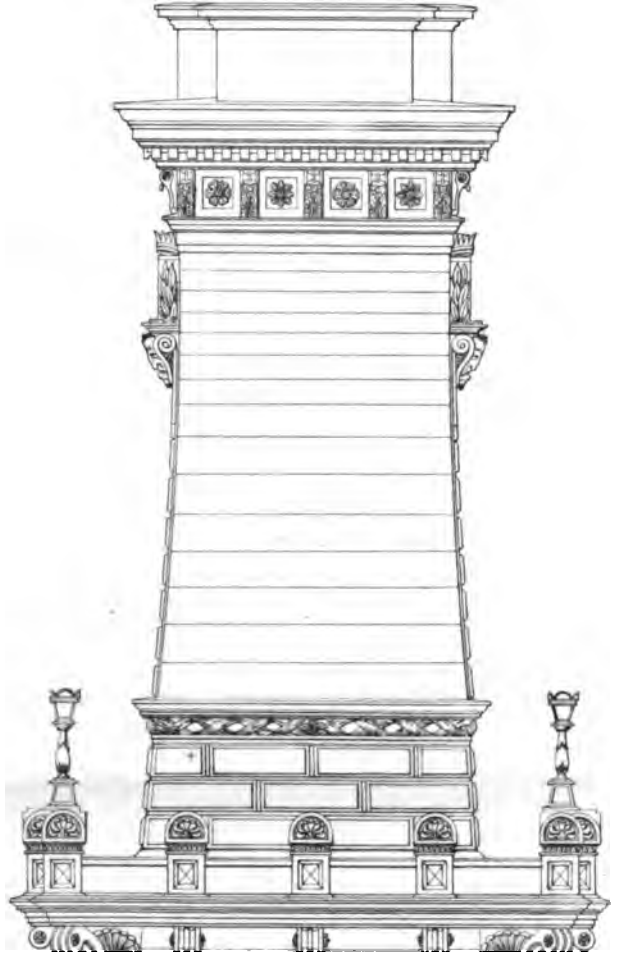
VERTICAL CROSS SECTION
OF Nº.S 2 AND 3 PIER
SHEWING VERTICAL BOND STONES.

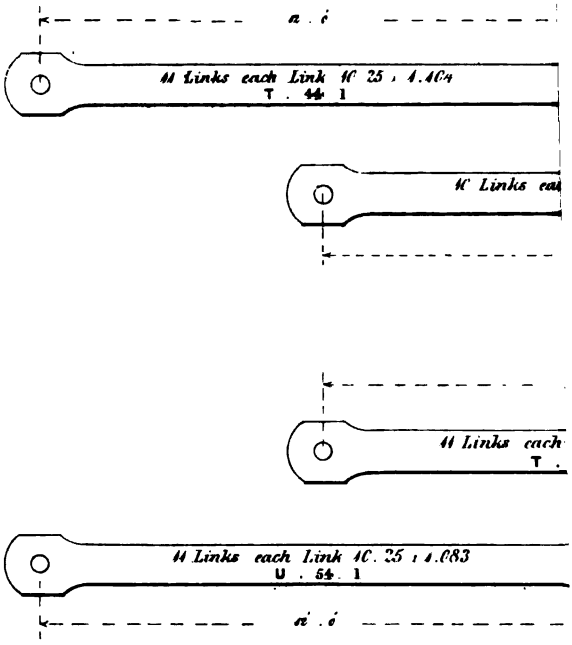


FRONT VIEW OF PIER.



ELEVATION OF END VIEW
OF Nos 2 AND 3 PIER.

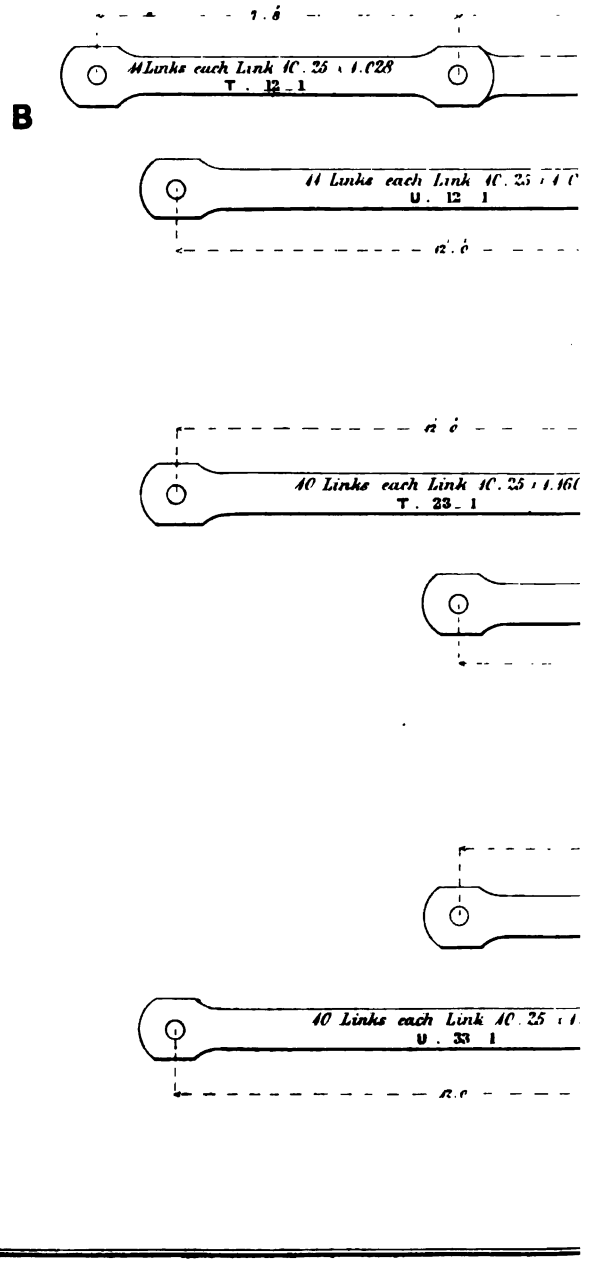


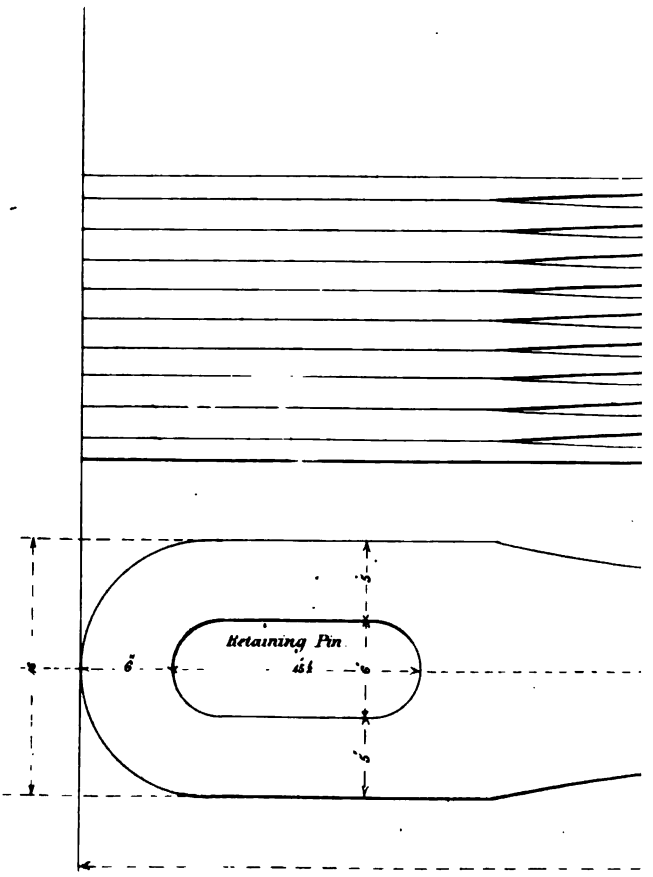


The several dimensions figu
of the different Links in h

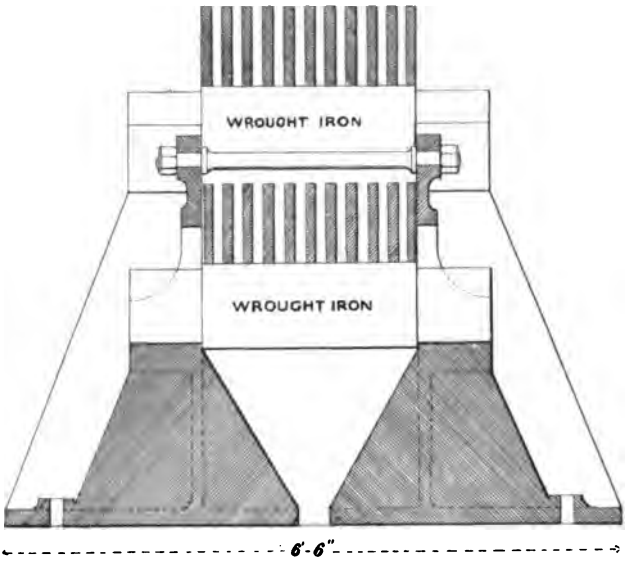
The Retaining Bars to be 3ft
of the form as shewn belo

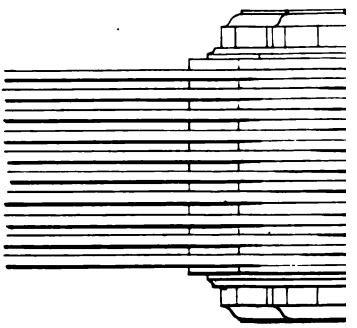
Continuation of Detail of Chain from head of Retaining Pier.


B
44 Links each Link 10. 25 × 1.028
T . 12 - 1
44 Links each Link 10. 25 × 1.0
U . 12 1
40 Links each Link 10. 25 × 1.160
T . 23 - 1
40 Links each Link 10. 25 × 1.
U . 33 1

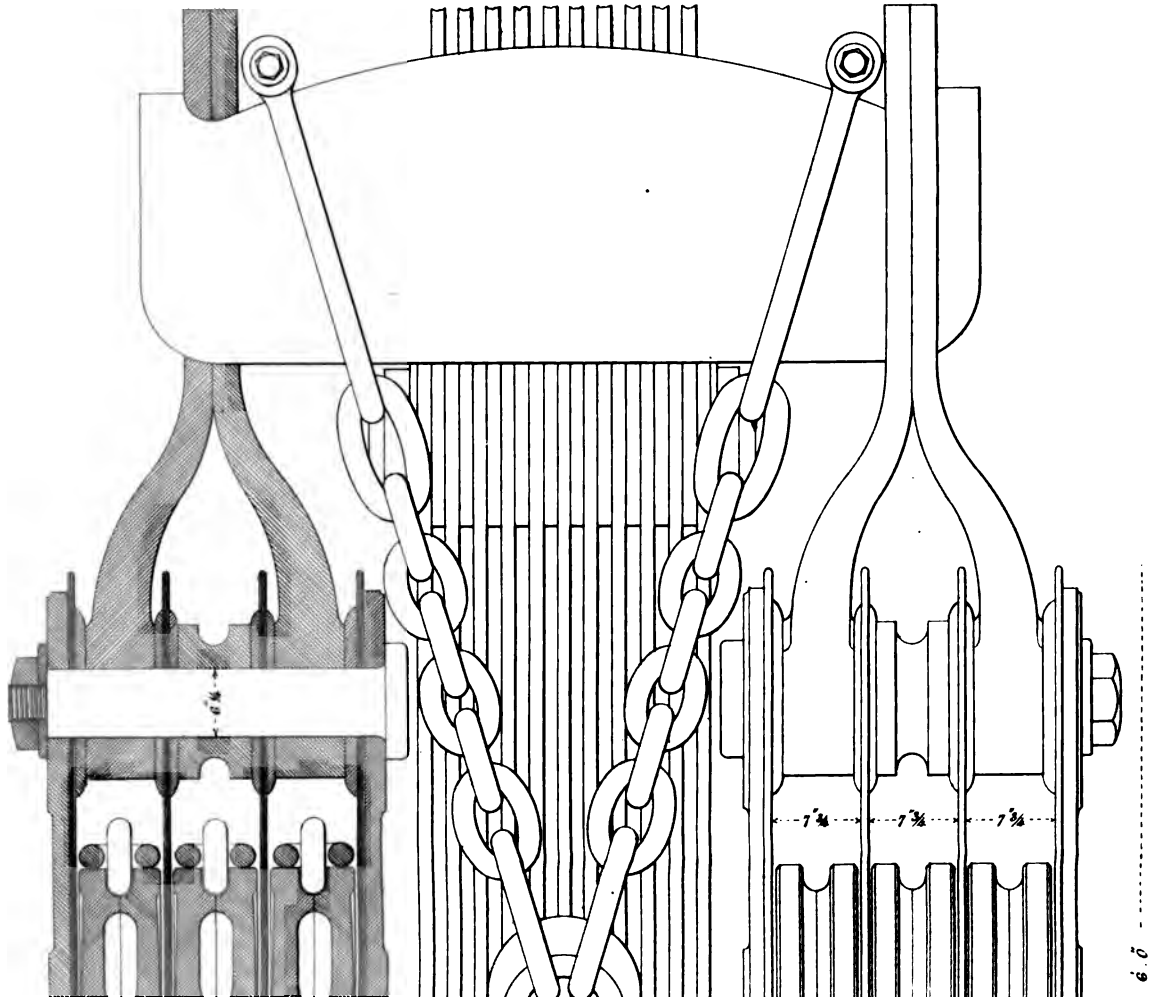

Retaining Pin
6"
4½"
3"
3"

END VIEW OF ROLLER FRAME.

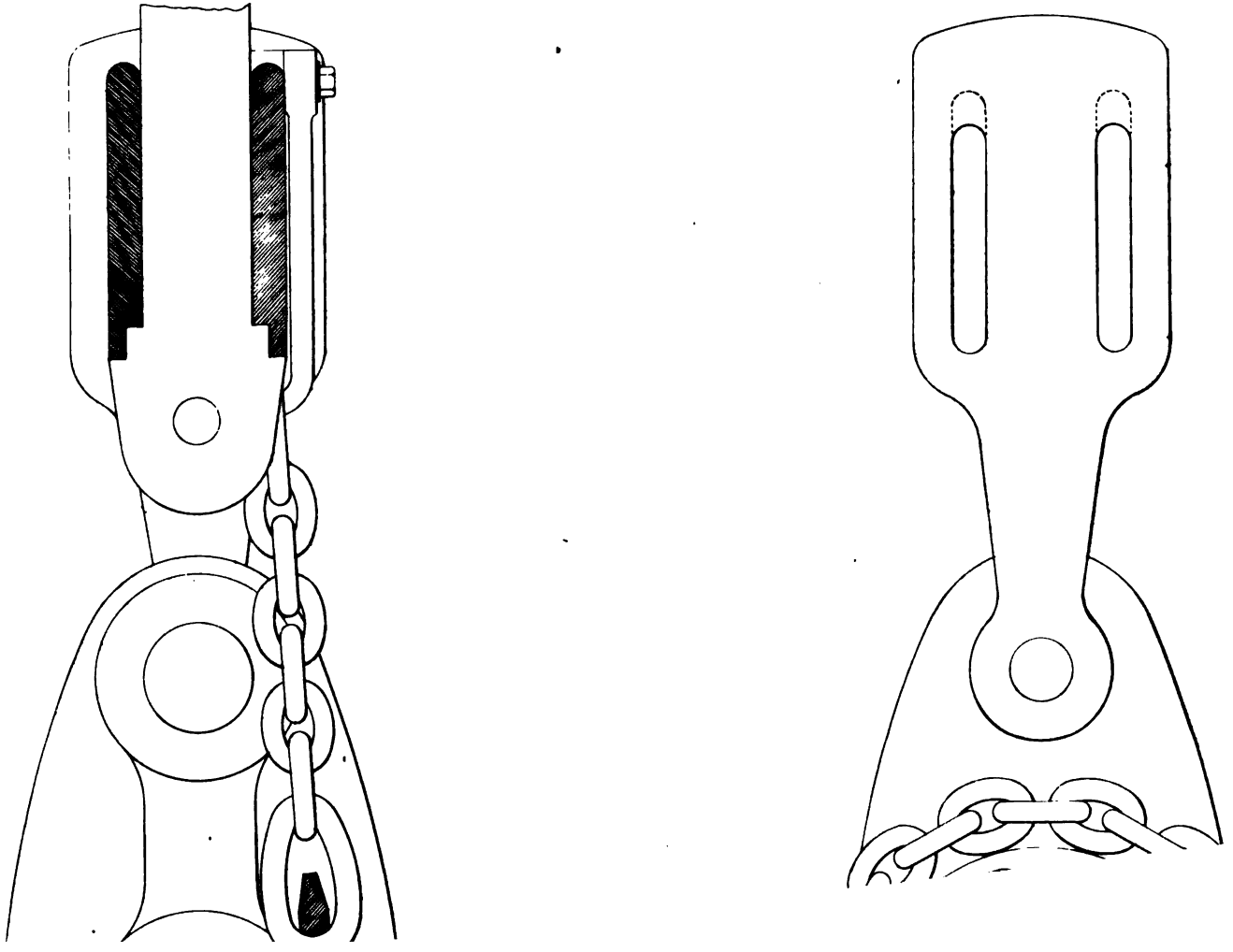




ELEVATION AND SECTION
OF A MAIN BLOCK FOR RAISING THE CHAINS.



ELEVATION AND SECTION
OF A MAIN BLOCK FOR RAISING THE CHAINS.



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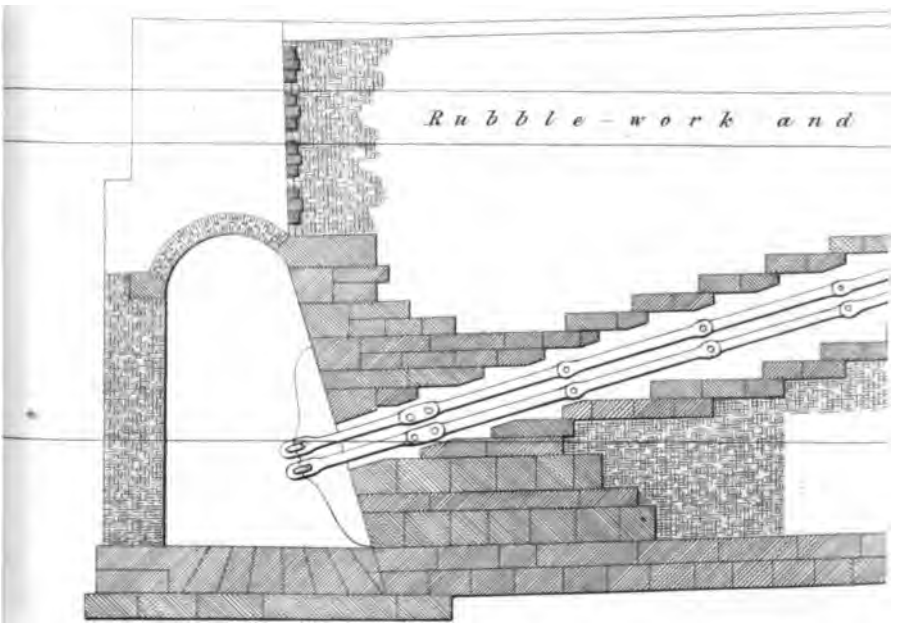
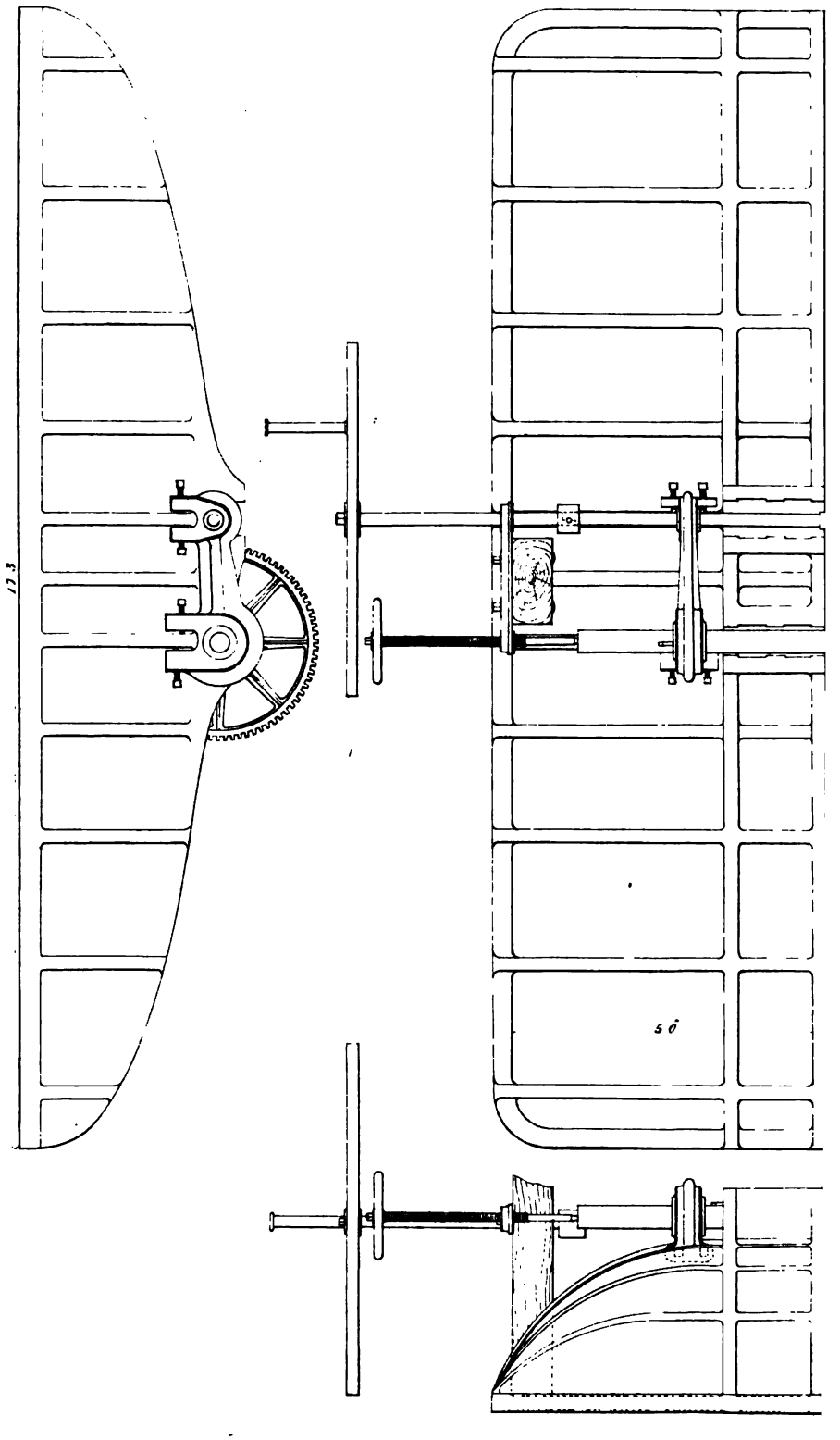
SHE



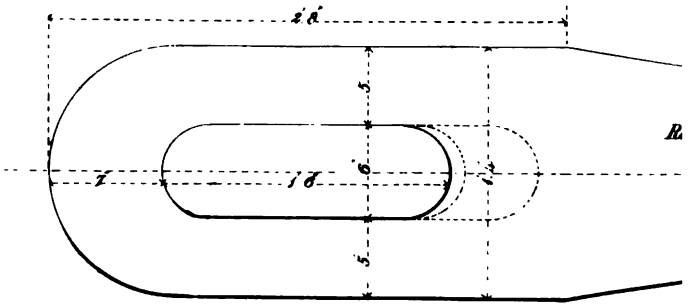
K098765-6210 IC

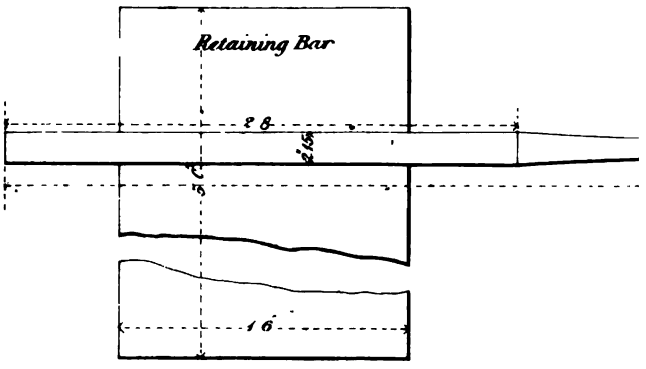
PLAN AND ELEVATIO

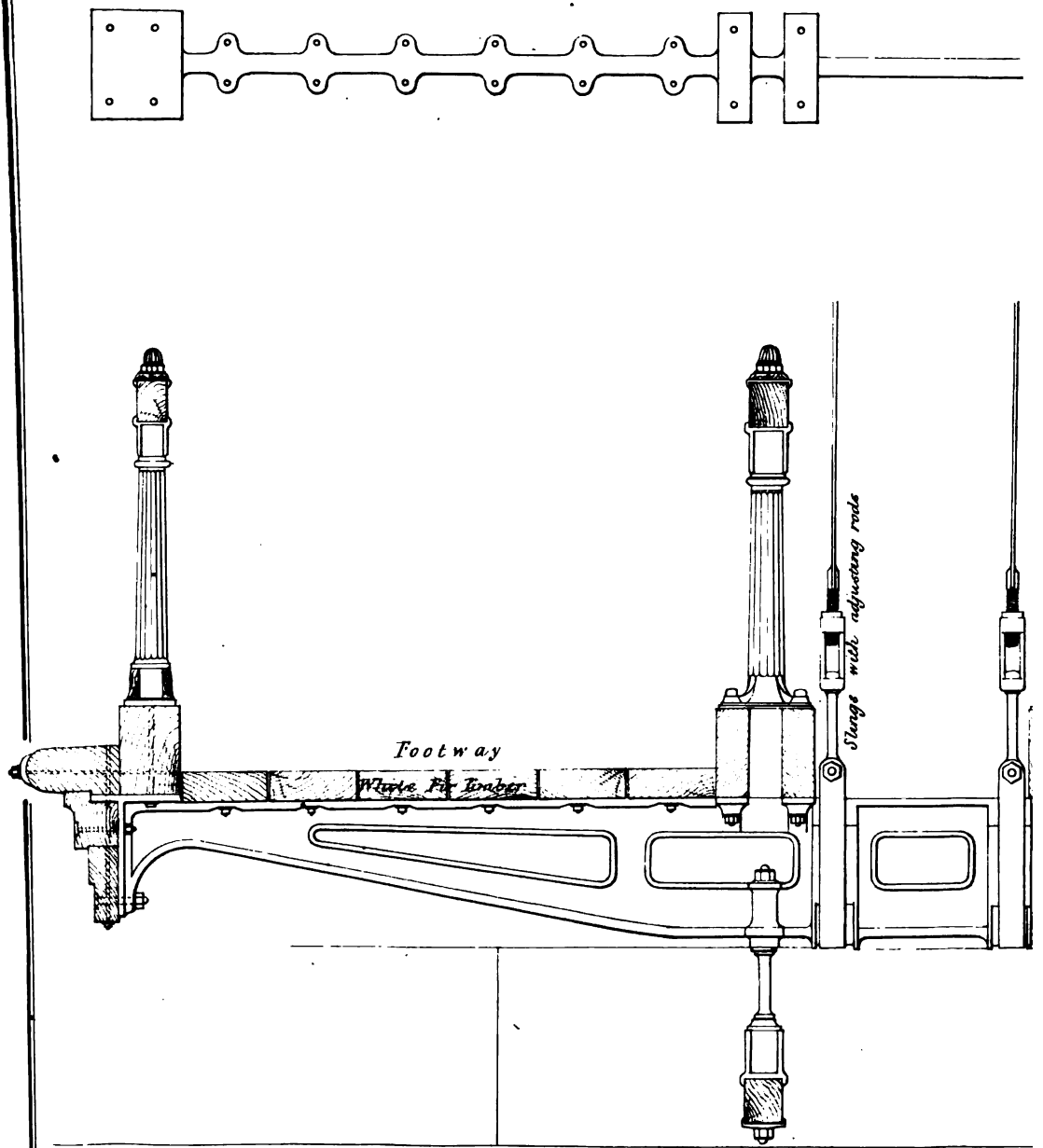
Shewing Machines for bo



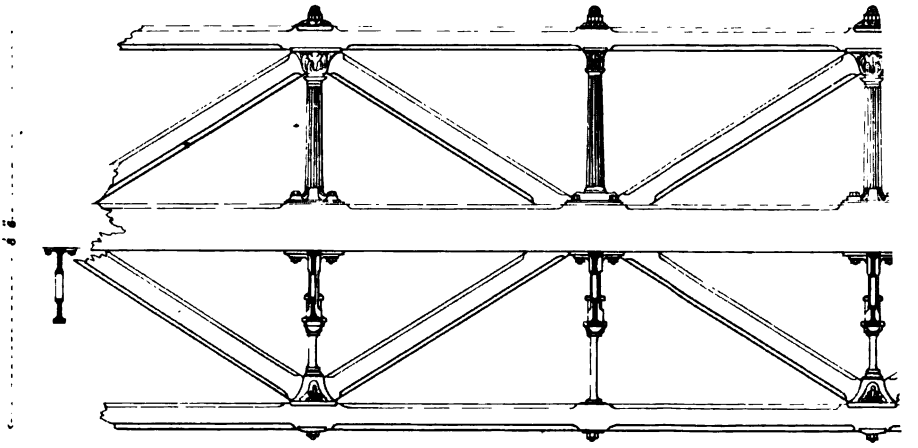
DRAWI



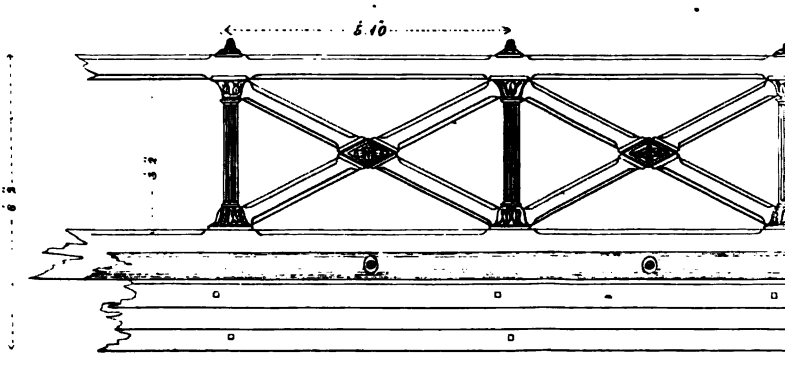



Footway
Whole Fir Timber
Slings with adjusting rods

LONGITUDINAL ELEVATIC



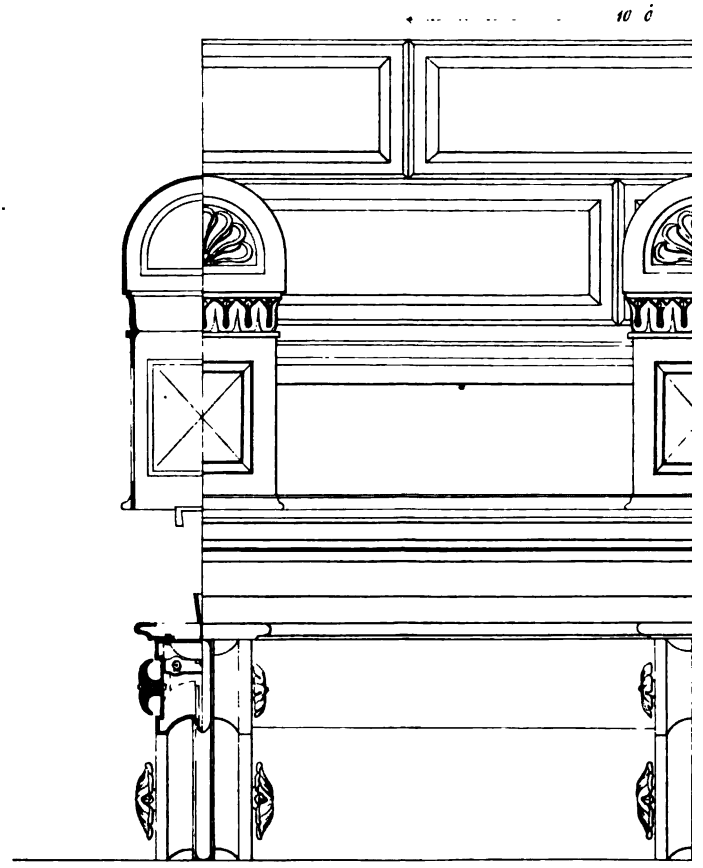
LONGITUDINAL E



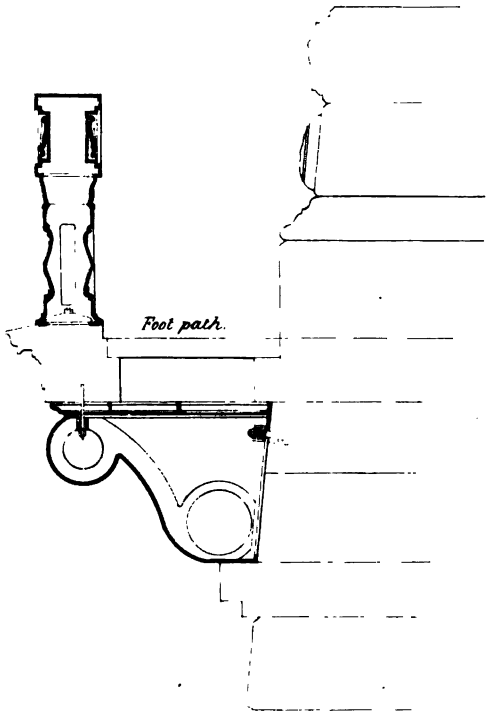
Published by Joh

DETAIL

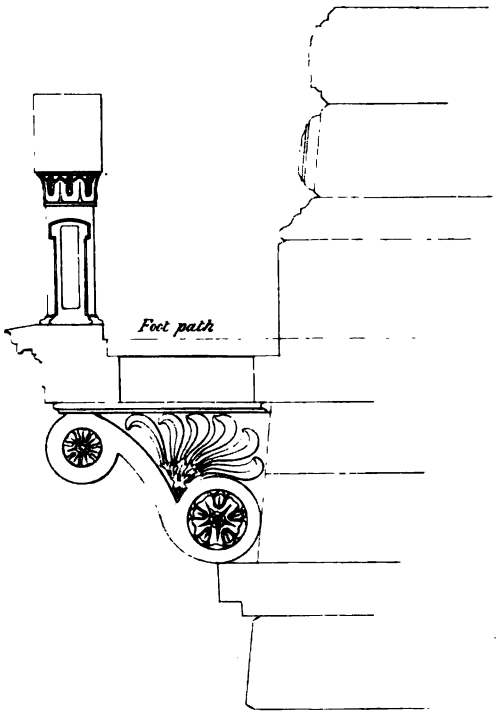
For suppor



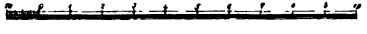
SECTION OF CANTILEVERS AND BALCONY.



ELEVATION OF CANTILEVERS AND BALCONY.



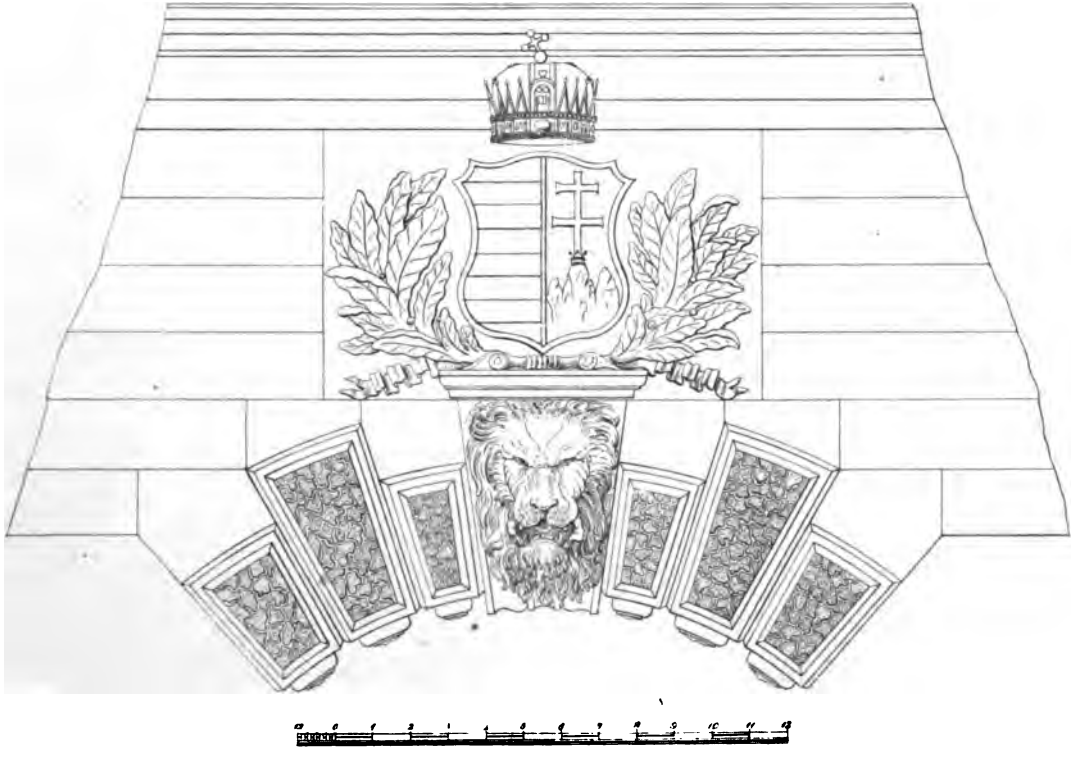
Scale of Feet.



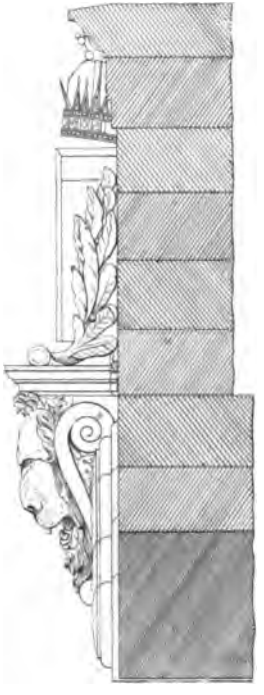
Standidge & Co Litho, Old Jewry.

Published by John Weale, London. May 1st 1862

DETAIL OF KEY STONE AND HUNGARIAN ARMS.



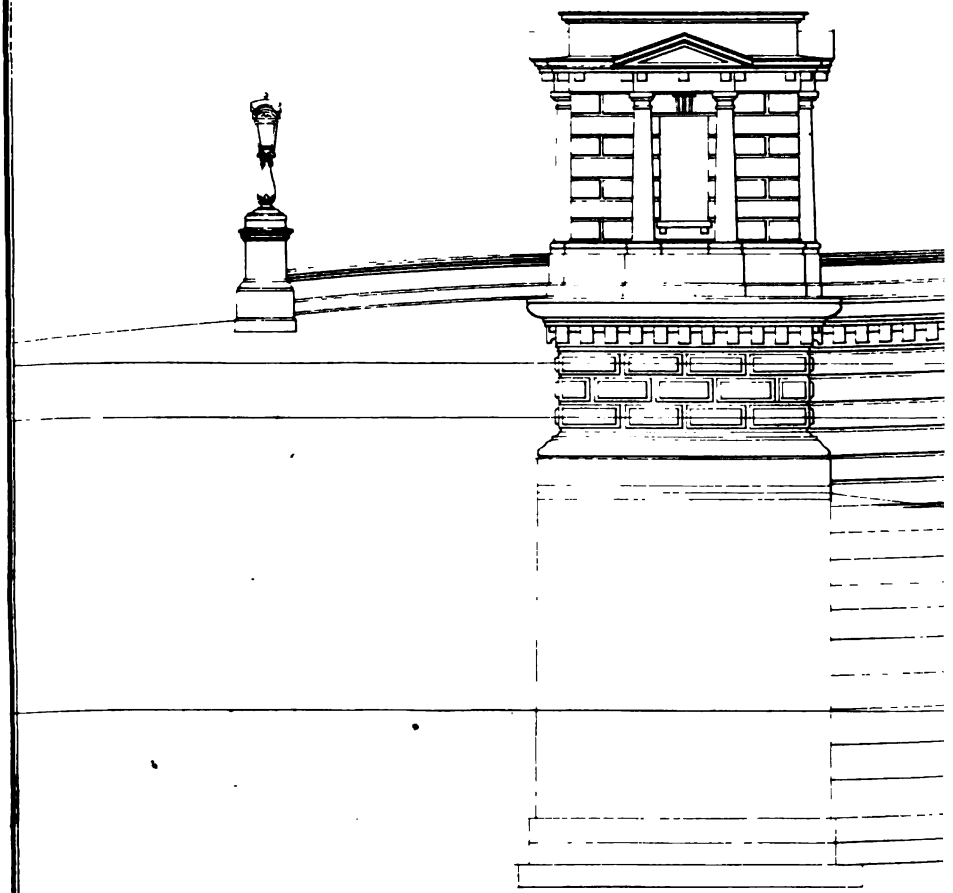
SIDE VIEW.



Standidge & Co Lithrs London

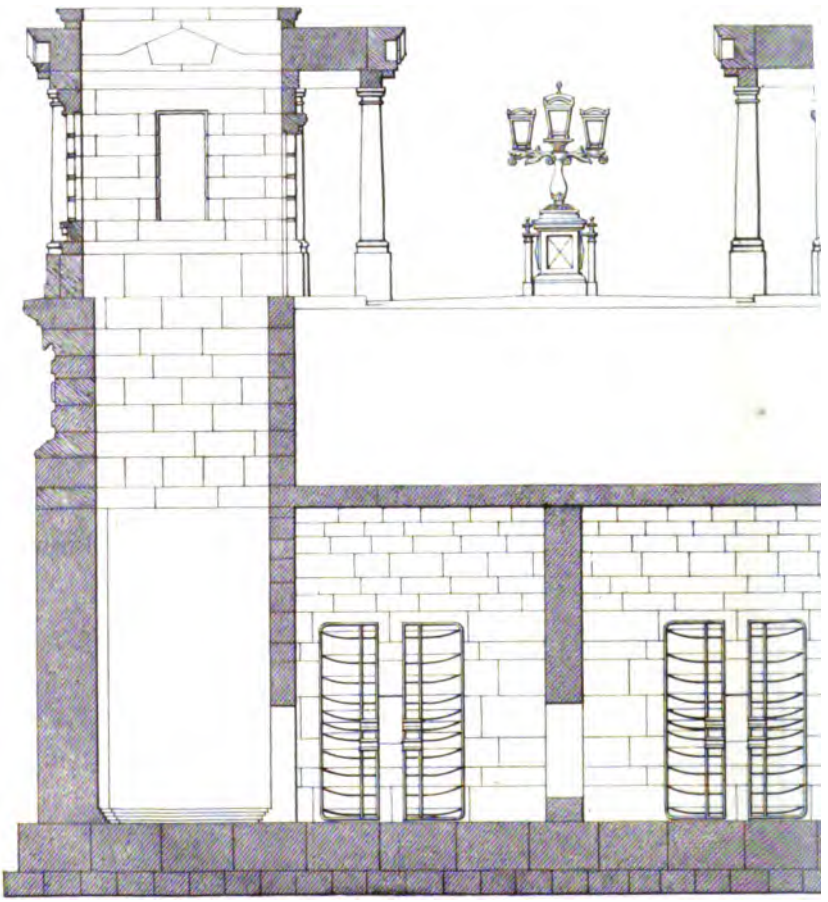
Published by John Weale, London. May 1st 1852.

LONGITUDINAL ELE



VERTICAL SECTION OF RETAINING-

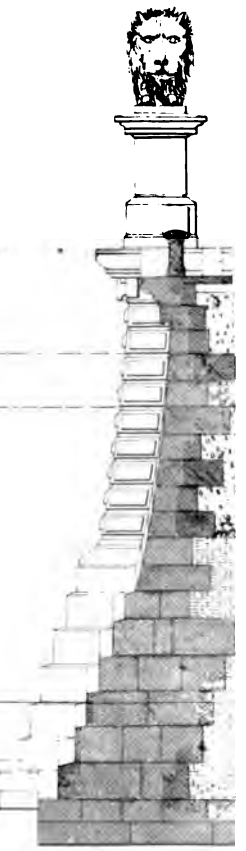
shewing Retaining Plates and Toll House



Scale of Feet.

0 1 2 3 4

SECT



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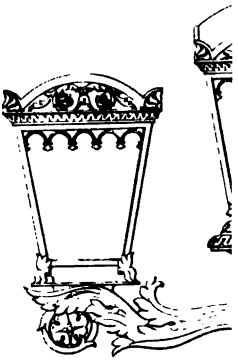
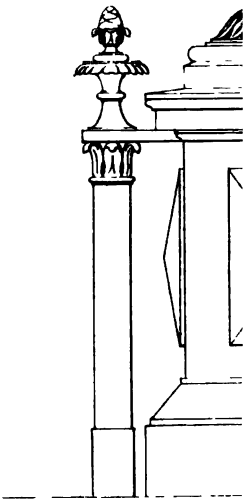
AT THE ENT





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